OTTO VON GUERICKE UNIVERSITÄT MAGDEBURG

FAKULTÄT FÜR WIRTSCHAFTSWISSENSCHAFT

# Problem description to seminar paper

# Scheduling last-mile deliveries with truck-based autonomous robots


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# 1. Introduction

The modern mix of transportation has changed dramatically in recent years owing to environmental and safety concerns as well as congestion in cities. This has driven innovation in this space as well, most notably electric vehicles (Pelletier, Jabali, & Laporte, 2016) for goods distribution and drones for freight delivery (Murray & Chu, 2015) at smaller scales. This has guided research in the direction of autonomous delivery robots which can transport goods from the warehouses to the customers in dense city centres.

This seminar focuses on one such innovative solution, a truck-based autonomous robot delivery system. In our model, the truck is going to carry the autonomous robot(s) from a centralised depot and make multiple stops in city centres, deploying one or more of those autonomous robots to carry the parcel to the customer (Boysen, Schwerdfeger & Weidinger, 2018). After the delivery is completed, the robots then return to the decentralised robot depots, where they can be refilled for the truck to once again pick them up to continue with the deliveries.

The proposed model in this seminar is ideal for businesses looking for efficient last-mile solutions in urban spaces. For instance, meal-prep and ingredients delivery companies (like HelloFresh) who face strict delivery time constraints to ensure freshness. This seminar should demonstrate that delays can be reduced significantly by allowing robots to deliver parcels while the truck continues along its path, which should minimise idle time and maximise efficiency (Boysen, Schwerdfeger & Weidinger, 2018). The benchmarking against traditional delivery methods should further demonstrate the relevance of this seminar's solution model among the vast sea of other innovative solutions.

The aim of the seminar would be to create a scheduling algorithm that minimises delivery delays. The problem is analysed very rigorously to ensure the proposed solution is effective compared to traditional delivery mechanisms. Results show that the decentralised robot depot model offers significant efficiency gains over waiting-based operations, demonstrating the potential benefits of this innovative delivery system.

# 2. Problem description

The Truck-based Robot Delivery (TBRD) deals with a scenario where a truck delivers shipments to a certain number of customers using autonomous robots which are launched from the said truck. This problem is especially relevant in settings where city centre congestion is a common occurrence, or if there are road restrictions in densely populated regions which makes delivery by smaller delivery agents necessary.

Problem components:

One of the problem components is the truck, which serves as a mobile depot, and starts at an initial known location with a certain number of robots onboard. Then, there are a certain number of customers, each with their own respective deadlines and penalty weights, which is the cost of late delivery. There is also the total travel time is characterised by the speed of the truck and the speed of the robots, which would be closer to pedestrian walking speed There are also 3 different types of locations:

- Customer location: this is visited by the autonomous robot only. It is important to note that the truck itself does not visit this location
- Drop off points: This is where the truck stops and launches the autonomous robots
- Robot depots: This is where the truck can go to reload itself with the robots, up to the maximum number of robots it can carry

Decision variables:

The first thing that needs a decision about is the truck route, deciding on what sequence of stops the truck needs to take, keeping in mind the following 2 things:

- The location from which the robots are launched from
- The subset of customers that can be served, given a certain location from which the robots are launched (above)

Objectives & Constraints:

The main goal of the TBRD problem is to create such a route for the truck, as well as a robot launching schedule that it optimises for minimising the weighted number of late deliveries. This objective is to be achieved keeping the following constraints in mind:

- All customers must be supplied
- Each customer is served by only 1 robot launched from a specific location
- The initial location of the truck is going to be the first point in the truck's route
- The truck has a max capacity, meaning it cannot carry more than a certain number of robots

- Hence, once the truck has been emptied, it needs to visit a robot depot to replenish itself, once again, up to the truck's max capacity

Problem Complexity:

The TBRD can be implied to be a NP-hard problem, given that we can reduce the Travelling Salesman Problem (TSP) (Garey & Johnson 1979) to TBRD. The proof can be implied in the following manner:

- The starting point of TSP can be mapped to the truck's initial location in the TBRD, and each city denoting a customer drop-off point
- The path truck takes to ensure timely delivery mirrors the path required in the TSP

This transformation allows us to infer the NP-hardness of TBRD problem, implying that finding an optimal solution via pure computation might be difficult (given a certain time constraint), thus necessitating the need for heuristics or other approximation methods.

The following assumptions go into the TBRD model before the transformation to TSP can be done:

- The truck is merely a launching point for the robots and does not do any of the deliveries to any of the customers
- The travel times for both the truck and the robots are assumed to be deterministic
- Truck stop times at the depot and drop off points are not incorporated
- Unrestricted robot availability is assumed, implying that the trucks can be replenished at the depots without any waiting times
- Deliveries require customers to be available at specific times
- The model also assumes a single delivery truck and a fixed and unchanging set of customers

# 3. Solution method

The main solution approach for the TBRD problem in this seminar will be based on a mixed-integer linear programming (MILP) model and metaheuristic optimization (Boysen, Schwerdfeger & Weidinger, 2018). Both will draw from methods already available in the body of literature on vehicle routing and delivery scheduling. This seminar will reference recent works that apply MILP for vehicle routing with deadlines and robot-assisted deliveries. The seminar will also reference studies that implement metaheuristics like, simulated annealing

(Lin, Vincent, & Chou, 2009) and variable neighbourhood search (Boysen, Schwerdfeger & Weidinger, 2018) to handle large problem instances where exact solutions aren't computationally possible.

Relying solely on Gurobi for exact optimization wouldn't be ideal given the NP-hard nature of the TBRD problem (Garey & Johnson 1979), especially for larger sets. We'll use a smaller set since it can be useful for benchmarking solutions, but given the scalability limitation, metaheuristics would be used for reasonably larger sets. This should allow us to explore a vaster solution space in a reasonable amount of computation time. Taking both simultaneously should provide us with a balanced framework for accuracy and scalability.

## Appendix A: Overview of relevant literature

| **Authors** | **Problem characteristics** | **Objective** | **Solution approach** | **Comment** |
|---|---|---|---|---|
| Murray & Chu, 2015 | Drone-truck delivery coordination | Minimise delivery time | Mixed-integer programming, heuristics | |
| Pelletier, Jabali, & Laporte, 2016 | Electric vehicles in logistics | Enhance green distribution practices | Literature review and analysis | |
| Boysen, Schwerdfeger & Weidinger, 2018 | Truck & autonomous robots delivery mechanism | Minimise weighted late deliveries | Mixed Integer Linear programming, metaheuristic | |
| Garey & Johnson 1979 | Computational complexity classification | Prove NP completeness | Reduction based proof techniques | |
| Lin, Vincent, & Chou, 2009 | Truck trailer routing constraints | Minimise routing costs | Simulated annealing heuristic | |

## Appendix B: Preliminary structure

**Introduction**

- Overview of urban delivery challenges.
- Introduction to truck-based autonomous robot concept.
- Objectives of the study.

**Literature Review**

- Innovations in last-mile delivery.
- Comparison with drone-based delivery.
- Relevant mathematical models and scheduling problems.

**Problem Definition**

- Description of truck-based robot delivery model.
- Constraints and assumptions.
- Formulation of the scheduling problem.

**Solution Methods**

- Mixed-Integer Programming (MIP) formulation.
- Heuristic approach and optimization techniques.
- Comparative methodology.

**Managerial Implications**

- Impact of depot/drop-off density, robot speed, and truck capacity.
- Benchmarking against alternative delivery strategies.

**Conclusions**

- Summary of findings.
- Future research directions.

## References


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