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1 Introduction

As both people and goods move in the urban environment, a successful integration of their streams has the potential of enhancing the quality of their existing transportation services as well as reducing congestion and pollution levels [1]. This paper considers an integrated system in which a set of freight requests need to be delivered using a fleet of grounded robots where a public transportation service (referred to as *scheduled line (SL)*) can be used as part of a robot's journey [1]. In addition, we consider that passengers and robots (carrying goods) share the same SL capacity where passenger demands are stochastic. Thus, depending on passenger demand realization, a robot might not be able to use the SL service and some recourse actions need to be applied. Thus, we develop a stochastic approach for operating this system and we perform an extensive computational study to analyze its performance and potential benefits.

2 Problem description

In this problem, a set of autonomous shuttles operate through a fixed-route scheduled line (SL) service for transporting passengers in both directions. This service consists of a set of transfer nodes (i.e. stations) and a set of scheduled lines linking them. Every SL has a capacity and a timetable. In addition, a fleet of grounded, pickup and delivery (PD) robots are located at transfer nodes to serve freight requests. Each PD robot has a capacity and a maximum service distance indicating the maximum distance it can go from a transfer node. Moreover, SLs and PD robots are associated with a shipping cost per one time unit.

Furthermore, a set of freight requests need to be delivered using the fleet of PD robots. Each request is associated with an origin, a destination, pickup and delivery time windows, and a demand quantity. Thus, each request has to be served within its corresponding time windows. Depending on the availability of vacant places, PD robots carrying freight may travel with passengers through SLs. Therefore, delivering a request can be done in either direct or indirect way. In a **direct delivery**, a request is delivered directly to its final destination by a PD robot without the use of SL (Figure 1a ; request a_1 is picked up at its origin o_{a_1} by a PD robot coming from transfer node s_2, and delivered to its final destination d_{a_1} before the PD robot returns to transfer node s_3). This direct delivery is only feasible if the distance between request origin and destination locations is less than the maximum distance the PD robot can travel.

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1. This integrated system was inspired from Toyota new e-Palette concept.

(a) Direct delivery - PD robot   (b) Indirect delivery - PD robot and scheduled line
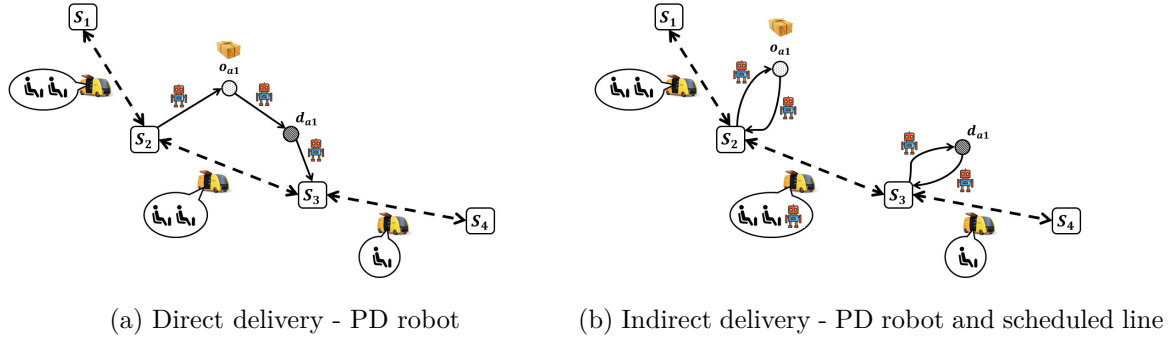
FIG. 1 – Request service modes : direct & indirect delivery

On the other hand, in an **indirect delivery**, a request is collected by a PD robot, transfered through SL, and delivered afterwards to its final destination by the same PD robot (Figure 1b ; request a_1 is picked up at its origin o_{a_1} by a PD robot, transported through SL from s_2 to s_3 and finally delivered to its final destination d_{a_1} by the PD robot). We assume that a passenger or a PD robot take over one place in a shuttle and that passengers are prioritized. For the sake of simplifying the problem, we assume that each PD robot can serve only one request at a time and that freight quantities are known in advance. On the other hand, passenger demand is only learned upon shuttles' arrivals to SL stations. Thus, the number of available places for PD robots at each SL departure is stochastic which might yield two capacity violation outcomes : *(i)* PD robot not being able to take the next SL departure due to the high passenger demand at the corresponding station, and *(ii)* PD robot having to get off the shuttle at an intermediate station in order to give its place to a passenger. When such route failures occur, recourse actions are needed in order to recover feasibility where applying these actions might lead to extra transportation costs compared to original routes.

3   Solution approach

Similar to [2], we model this problem as a two-stage stochastic problem, where the first-stage aims at defining routes for PD robots carrying freight, and the second-stage involves evaluating these routes over a set of scenarios and computing their recourse costs. Thus, we provide a MIP formulation for the proposed pickup and delivery problem where the overall objective is to minimize the sum of the routing and recourse costs. Then, we propose a *sample average approximation* (SAA) method along with an *Adaptive Large Neighborhood Search* (ALNS) algorithm to solve the stochastic optimization problem.

4   Conclusions

To conclude, our key contributions can be seen in the problem setting we consider, the modeling and solution approach we propose to handle it, and the experimental study we provide to assess its different aspects as well as the potential benefits of such combined systems.

Références

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