En-route truck-drone parcel delivery for optimal vehicle routing strategies

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INTRODUCTION

DELIVERY SYSTEMS USING DRONES

Amazon’s Prime Air

DHL Parcelcopter

Google Wing

Zipline

EN-ROUTE TRUCK-DRONE PARCEL DELIVERY FOR OPTIMAL VEHICLE ROUTING STRATEGIES

Caggiani – Marinelli – Dell’Orco - Ottomanelli
Politecnico di Bari - DICATECh – T@P Transportation At Poliba Research Group

SIDT 2017
INTRODUCTION

TRUCK-AND-DRONE PARCEL DELIVERY
**INTRODUCTION**

*Traveling Salesman Problem with Drone (TSP-D)*
## Existing approaches

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<th>Author</th>
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<td>Agatz et al.</td>
<td>2015</td>
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<td>MIP formulation solved by a heuristic in which drone or dynamic programming route construction is based on either local search.</td>
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<td>Ha et al.</td>
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<td>Traveling Salesman Problem with Drone (TSP-D)</td>
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<td>Wang et al.</td>
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<td>Fleet of trucks equipped with drones delivering packages to customers.</td>
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<td>Dorling et al.</td>
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<td>Vehicle Routing Problem with Drones (VRPD)</td>
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**Basic assumption:**

_Launch and rendezvous operations must be performed at customer nodes._
**Problem description and formulation**

In a truck-drone operation, the drone is launched from the truck and later re-joins the truck at another location.

We can represent a truck-drone operation by a 3-tuple \((v_i, v_j, v_k)\)

A truck-drone operation is called feasible if the drone has sufficient endurance to launch from \(v_i\), deliver to \(v_j\) and re-join the truck at \(v_k\).

Launch node \((v_i)\)

Drone node \((v_j)\)

Rendezvous node \((v_k)\)

Any possible truck node \((v)\) between node \(v_i\) and \(v_k\)
Problem description and formulation

**Integer Programming formulation as proposed by Agatz et al. (2015)**

\[
\begin{align*}
\text{min} & \quad \sum_{o \in O} c_o x_o \\
\text{subject to} & \\
& \quad \sum_{o \in O(v)} x_o \geq 1 \quad \forall v \in V \\
& \quad \sum_{o \in O^+(v)} x_o \leq n \cdot y_v \quad \forall v \in V \\
& \quad \sum_{o \in O^+(v)} x_o = \sum_{o \in O^-(v)} x_o \quad \forall v \in V \\
& \quad \sum_{o \in O^+(v)} x_o \geq y_v \quad \forall S \subset V \{v_0\}, v \in S \\
& \quad \sum_{o \in O(v_0)} x_o \geq 1 \\
& \quad y_{v_0} = 1 \\
& \quad x_o, y_v \in \{0, 1\}
\end{align*}
\]

**O**: set of feasible operations  
\(c_o\): cost of operation  
\(x_o\): operation \(o\) chosen or not  
\(y_v\): auxiliary variable
The new truck-drone operation is considered feasible if the following condition is satisfied:

\[ t_{i^*,j,k}^w(R) + c^* < t_{i,j,k}^w \]

\[ c^* \] is an additive cost for drone launch and rendezvous along the arcs.
POSSIBLE BENEFITS

Reduction of drone traveling time along a given 3-tuple.

Increase in drone remaining endurance with a consequent increase in battery life.

Increase in drone coverage and usage with a consequent reduction of total traveling costs.
The proposed heuristic

1. Solve the TSP problem (Lin-Kernighan heuristic)
2. Find all the feasible truck-drone operations (node-based) that can occur between a node pair \((v_i, v_k)\)
3. Improve to the truck-drone operations’ set considering en-route drone operations
4. Construct the TSP-D solution
   \[ c_o = c_{i,j,k} + t_{i,j,w} \]
Application and results

Numerical experiments are based on the benchmark instances by Bouman et al. (2016)

Instances with 10, 20 and 50 customers arranging the square region to 15 by 15 km, 30 by 30 km and 50 by 50 km, respectively.

Each group is composed of 10 instances where customers are generated using a uniform random distribution.

Drone endurance was assumed to be 30 min.

Drone speeds have been selected as 40 or 60 km/h.

The truck speed was assumed to be 40 km/h.

The en-route operation cost $c^*$ was assumed to be one minute.
Application and results

Comparison of average savings over TSP route

$s_T = 40 \text{ km/h, } s_D = 40 \text{ km/h}$

$s_T = 40 \text{ km/h, } s_D = 60 \text{ km/h}$
Application and results

Comparison of average battery savings

S\textsubscript{T} = 40 km/h, S\textsubscript{D} = 40 km/h

S\textsubscript{T} = 40 km/h, S\textsubscript{D} = 60 km/h

En-route Heuristic
Greedy Heuristic

Avg. Battery Savings (%)

No. Customers

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**Application and results**

Comparison of average waiting time

![Comparison of average waiting time](image)

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Application and results

Initial TSP solution

Greedy heuristic solution

En-route heuristic solution
Conclusions

The problem is of current interest, and many logistic companies are seriously considering this new concept in parcel delivery.

We have introduced the possibility of performing truck-drone operations also along arcs, called en-route operations.

The obtained results have highlighted the effectiveness of the proposed approach and give new ideas for further works.

Future developments

A dynamic simulation model can be developed considering en-route operations in urban traffic networks.

We can consider performing these operations also when the truck travels along congested arcs, significantly reducing total transportation costs.
THANK YOU
FOR YOUR ATTENTION

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