Cost Optimization
For the unmanned aircraft delivery system with Public Transportation

vehicle routing problem

Miae Kim

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Computer and Information Technology

General Overview

Drone delivery system uses UAV's instead of delivery driver

There are still some obstacles for delivery system.

- Deliver one item at a time

Figure 1: deliver back and forth

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    - Most UAV's have maximum 90 minutes of battery life [1]

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    - If drone deliver packages, expected battery life will be reduced

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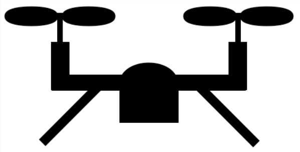
Introduction

Statement of Problem

What if UAV’s can exploit current transportation system?



Adapting public transportation makes delivery system be able to deliver multiple packages at a same time and it reduces the total time of delivery.

Therefore, the new rendering algorithm will deliver massive packages in limited time by reducing cost.

> *What is the effect of a having the transportation system on the drone delivery system?*

Toy example

For example, when a UAV delivers five packages from warehouse w to destination d, which is the cheapest way to deliver the packages?

We can think of three ways to deliver the packages.

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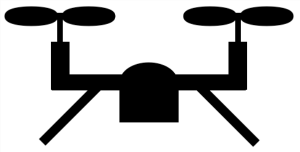
- Use only UAV's to deliver the packages
- Use public transportation to deliver packages to the nearest bus stops then deliver packages with UAV's
  – the optimization algorithm will approach in this way

Assumptions - UAV



- Every UAV can deliver only one package at a time
- Every UAV can fly up to 15 minutes with its battery
- Every UAV can charge itself on top of the bus
  - The bus has the charging board on top of the bus and the bottom of the drone.
- Every UAV in this paper is a vertical take-off and landing (VTOL) aircraft. In this study, the drone have average speed of 15 km/h.

Assumptions - Others

- Every agents already know where the bus is based on bus schedule.
  - The schedule is easily obtained in the homepage of the bus company. The average speed of bus is 14 km/h [2].
- Customer demands are known in advance.

Literature Review

TSP and VRP

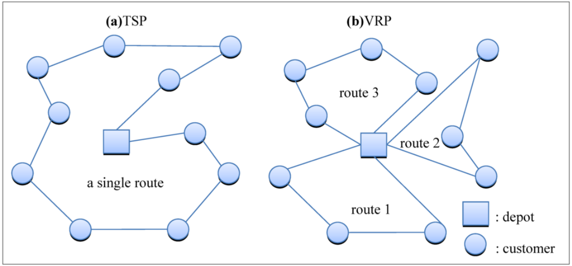


Figure 2: image source: http://www.mdpi.com/2071-1050/6/7/4658/htm

Find the most minimum traveling distance

TSP is a simple model of VRP

- one vechle
- no capacity
- no time windows, etc

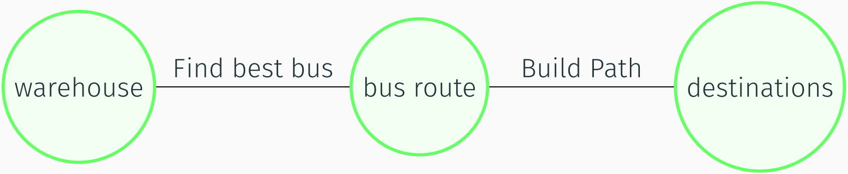
How to solve VRP

VRP is NP-hard problem

- Brute force
- Linear programming
- Heruistic approach

Methodology

Study Design



- Find the optimal bus route

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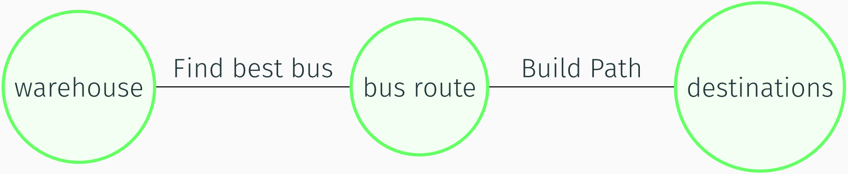

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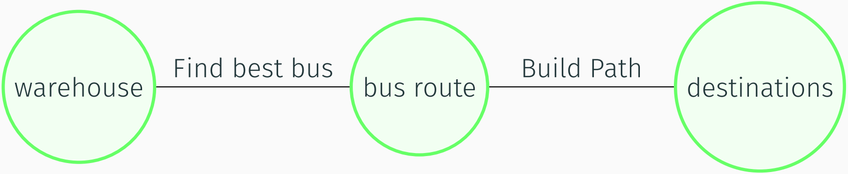

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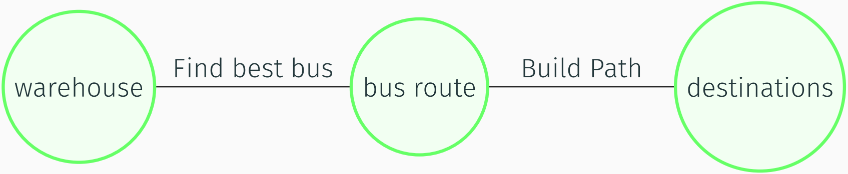

- Find the optimal bus route
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  H_{O1}: The bus route has nothing to do with the total cost of delivery.

  H_{A1}: Proper bus route reduces the total cost of delivery.

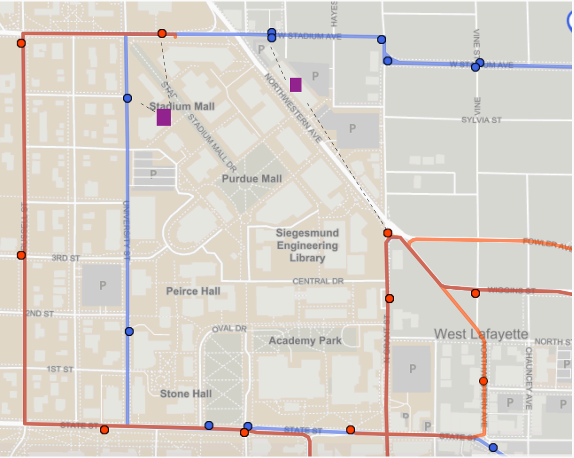


Figure 3: Campus bus route and customer demand

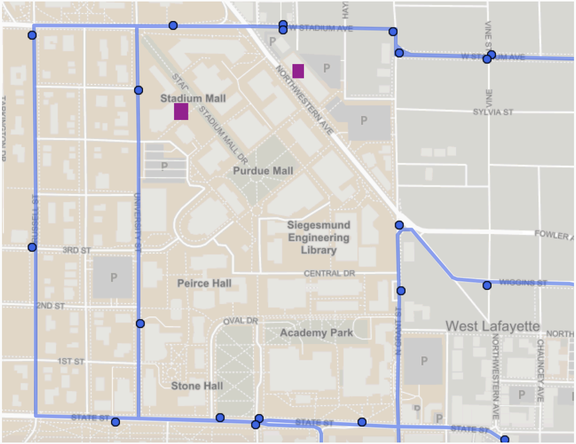
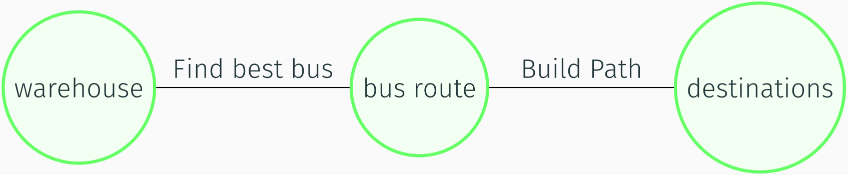


Figure 4: After route selection

Study Design



- Given bus with packages, build path from bus to the destination

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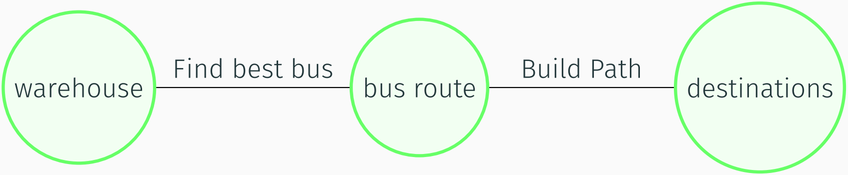

- Given bus with packages, build path from bus to the destination
    - Calculate distance between the bus stop and build pairwise distances

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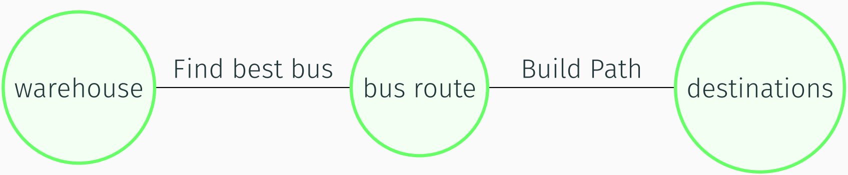

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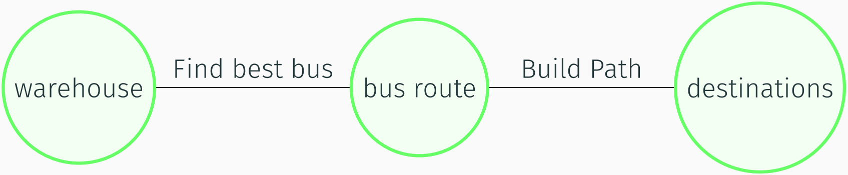

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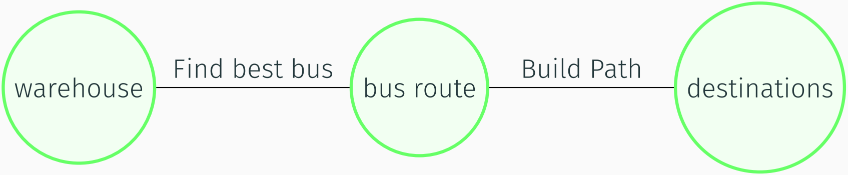


- Given bus with packages, build path from bus to the destination
  - Calculate distance between the bus stop and build pairwise distances
  - build graph model
  - VRP with Pickup and Delivery(VRPPD)

  H_{O2}: The routing algorithm will not reduce running time of UAV's by delivering multiple package at a time

  H_{A2}: The routing algorithm will reduce running time of UAV's by delivering multiple package at a time

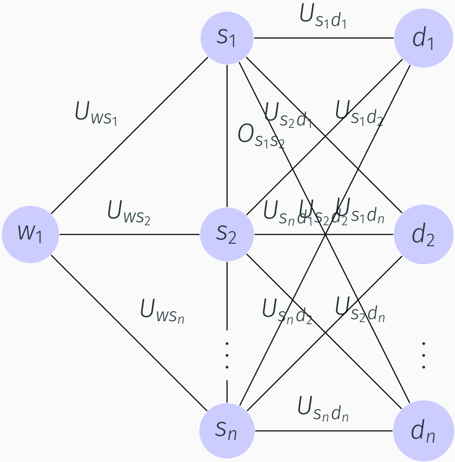
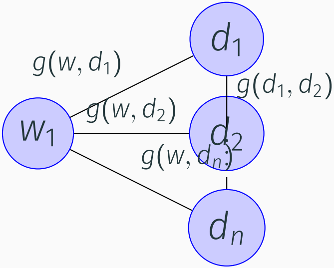


Figure 5: Simplified transportation graph

w_1 is a warehouse, s_n is n-th bus stop and d_n is n-th destination.

Build Path - Convert Graph



$$\text{minimal cost through bus } c_{wd} = \min_{ij \in S} U_{wi} + O_{ij} + U_{jd} \qquad \text{where } i, j \in S \tag{1}$$

Convert graph by removing bus stops and update distances to accumulate them as stopovers

This converted graph is compatible with Traveling Salesman Problem(TSP).

Experiment Design

Goal

- to find the cost-effectiveness threshold of the number of packages compared to the current UAV's delivery system.

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- to find the cost-effectiveness threshold of the number of packages compared to the current UAV's delivery system.
- to find the best route for the UAV's delivery with the public transportation

```
minimize total mileage of UAV's
```

$$\min \sum_{i}^{V} \sum_{j}^{V} x_{ij} c_{ij} \tag{2}$$

$$W = \{w_1, w_2, \cdots w_m\}$$
$$D = \{d_1, d_2, \cdots d_n\} \tag{3}$$
$$x_{ij} = \begin{cases} 1, & \text{path from } i \text{ to } d, i \in W \cup D, j \in D. \\ 0, & \text{otherwise.} \end{cases}$$

Variables

Independent variables

- The number of customers' orders
- The number of UAV's
- The delivery method
- Routing algorithm

Dependent variables

- Total time consumed for delivery
- Total mileage of each UAV
- Delivery range of the system

Analysis

- Treatment group
  - Deliver with bus and UAV
- Control group
  - Deliver with UAV
- Effect Size

$$\frac{\text{mean of treatment group} - \text{mean of control group standard}}{\text{deviation of control group}} \tag{4}$$

  - $<$ 0.1 = trivial effect
  - 0.1 – 0.3 = small effect
  - 0.3 – 0.5 = moderate effect
  - $>$ 0.5 = large difference effect

Simulation environment

- Purdue University campus area
    - map data
    - bus route
    - bus schedule
- randomly scatter customer demand
- repeat 1000 time
- UAV
    - run for 15 minutes
    - average speed is 15km/h
- Average speed of bus is 38km/h

Questions?

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Technical report, 2009.