Nature Inspired Optimisation for Delivery Problems
Chapter 5: Solving Problems that have Multiple Solution Characteristics

Neil Urquhart

May 27, 2022

These slides are designed to accompany the book "Nature Inspired Optimisation for Delivery Problems : From Theory to the Real World".

https://link.springer.com/book/10.1007/978-3-030-98108-2

Last Mile Deliveries

Trends in Logistics

- The growth in the on demand economy has dramatically increased business to consumer (B2C) deliveries of goods and services to the homes of consumers.
- Data released by the United Kingdom Office of National Statistics (ONS) suggests that online purchases have increased from 7.7% of UK retail sales in July 2011 to 26% in July 2021 and reaching 36% in December 2020.
- The final step in the supply chain to the home of the consumer is often referred to as the *last mile*

Problem Characteristics

When solving a typical last mile problem, the factors that may have to be taken into consideration include:

- **Financial** - capital costs, running costs, energy costs, staff costs
- **Environmental** - CO_2 emissions, congestion
- **Customer Service** - delivery time windows
- **Delivery Technologies** - Vans, Cargo Bikes, Walking couriers etc

We can formulate such problems as *multi-objective* problems.

Multi-Objective Problems

Multi-objective problems may be solved in a number of ways:

- The objectives may be combined by using weights (see section to create a single value to be optimised
- A set of solutions may be identified to allow an expert user to make the final choice of solution.

We will use the terms *problem characteristic* and *problem objective*. For our purposes we adopt the following definitions;

- *objectives* are attributes within the solution that the user is actively interested in controlling.
- *characteristics* are attributes within the solution that the user is not directly interested in, but which help describe the solution.

The Vehicle Routing with Time Windows

Vehicle Routing Problems

Many of the home delivery services offered by supermarkets and other providers allow the customer to specify that the delivery is to be made within a given time window, leading to many variants, a brief but by no means exhaustive list of common variants includes:

- **CVRP** - Capacitated Vehicle Routing Problem
- **VRPTW** - Vehicle Routing Problem with Time Windows, each customer must be visited within a specified hard time window.
- **CVRPTW** - Capacitated Vehicle Routing Problem with Time Windows

...

Vehicle Routing Problems ... cont

Many of the home delivery services offered by supermarkets and other providers allow the customer to specify that the delivery is to be made within a given time window, leading to many variants, a brief but by no means exhaustive list of common variants includes:

- **DVRP** - Dynamic Vehicle Routing Problem, Customers are added to the problem at run time.
- **VRPSTW** - Vehicle Routing Problem with Soft Time Windows , Customers are allocated a long soft time window and within that a short hard time window deliveries are penalised for missing the hard time window.

The Capacitated Vehicle Routing Problem with Time Windows

We will examine the Capacitated Vehicle Routing Problem with Time Windows (CVRP)
Each customer delivery must take place within a time window. Customer c_i has a time window denoted by a start time s_i and a finish time f_i.This results in the following constraint:

$$s_i <= d_i <= f_i$$

- The delivery time of customer i must fall within the time window of customer i. Any solution that has a delivery outwith the time window is an invalid solution.
- If the delivery vehicle arrives before the time window, then it may wait for the window to start.
- We must now consider time within our problem formulation and solutions.

A Case Study: A Home Delivery Service

Home Deliveries

A supermarket that decides to trial a home delivery service, they wish to have four objectives which they wish to take into account:

- **Distance** - The total distance of all of the routes within the solution.
- **Time** - The sum of the length of time for each route.
- **Routes** - The total number of routes within the solution.
- **Cost per Crate** - The cost for each Crate delivered

Orders are delivered in *crates* each order comprises one or more crates of groceries and other goods.

Costing Model

FabFoods have a costing model for their proposed deliveries which allows the cost/Crate to be calculated as follows:

$$vehicleCost = (noRoutes * VFIXED) + (totalDistance * VRUNNING)$$
$$staffCost = (totalTime * STAFF\_RATE)$$
$$solutionCost = vehicleCost + staffCost \quad costPerCrate = \frac{solutionCost}{totalDemnd}$$

We assume that one vehicle is required per route and one member of staff is required per vehicle. Staff are paid from when the vehicle leaves the depot until when it returns.

Representation and Decoding

- The same representation as described in the previous chapter is used
- An updated decoding mechanism is required
- The updated decoder calculates the arrival time at each customer as they are added to the solution.
  - If the arrival time is early then the vehicle waits at the customer until the customer is ready (known as *waiting time*).
  - If a vehicle arrives at the customer beyond the time window then a new route is started and the customer added to the start of that route.

Representation and Decoding: Example

For example let's assume that the we have the following set of customers:

ID	Window Start	Window End	Requirement
1	09:00	10:00	5
2	09:00	10:00	5
3	11:00	12:00	10
4	13:00	14:00	10
5	12:00	13:00	5
6	10:00	11:00	5
7	11:00	12:00	5
8	13:00	14:00	5

We also need a set of travelling times between locations and we allow 5 minutes per delivery.

Representation and Decoding: Example

Let us assume that we have the following genotype:

5,0	2, 0	4, 0	8, 0	1,0	7,1	3,0	6,0

The decoder creates the first route, and adds customer 5 to the head of it. The initial arrival time is based on 8 minutes travelling as customer 5 is not available until 12:00, the arrival time will be scheduled for 12:00

Route 1
5 @ 12:00

The next customer for adding to the solution is 2, the earliest arrival time is 12:20 (depart from 5 at 12:05 plus 15 minutes travelling time). As the last arrival time for customer 2 is 10:00, they cannot be added to route, therefore a new route is required:

Route 1	Route 2
5 @ 13:00	2 @ 09:00

Representation and Decoding: Example

The decoder continues to process the next two genes, further adding to route 2:

Route 1	Route 2
5 @ 13:00	2 @ 09:00
	4 @ 13:00
	8 @ 13:25

Representation and Decoding: Example

As route 2 is now at capacity, next delivery will have to be added to a new route, the decoder processes the rest of the genotype and produces the following phenotype:

Route 1	Route 2	Route 3	Route 4	Route 5
5 @13:00	2 @ 09:00	1 @ 09:00	7 @ 11:00	6 @ 10:00
	4 @ 13:00		3 @ 11:17	
	8 @ 13:25			

Note that route 4 is started as the genome specifies that customer 7 should be at the start of a new route.

The Final Solution

The final solution looks like this, for completeness we add in the depot departure and arrival times for each route (Note that we use the "*" symbol as a short hand for "departs at").

Route 1	Route 2	Route 3	Route 4	Route 5
D * 12:52	D * 08:50	D * 08:48	D * 10:55	D * 09:40
5 @13:00	2 @ 09:00	1 @ 09:00	7 @ 11:00	6 @ 10:00
D @ 13:17	4 @ 13:00	D @ 09:17	3 @ 11:17	D @ 10:13
	8 @ 13:25		D @ 11:34	
	D @ 13:53			

Note that there is is another potential layer of optimisation, it is possible for a single vehicle to operate Route 3, then Route 5 and then Route 4 and finally Route 1 assuming that there is sufficient time to re-load the vehicle in between runs.

Summary

Summary

- In this chapter we have introduced the concept of Time Window constraints
- The addition of time windows requires a modified decoder that can take into account the additional constraints
- Our CVRPTW problem can be solved using the same representation and operators as for the CVRP, but with the addtion of a modified decoder.
- When introducing a modified decoder care should be taken to avoid undue complexity as this can have a detrimental effect on runtimes.