2015 ACP SUMMER SCHOOL IN CONSTRAINT PROGRAMMING COMPETITION

INVENTORY REBALANCING FOR BIKE-SHARING SYSTEMS

Introduction

Bike-sharing, or *public bicycle program,* is a service in which bicycles are made available for shared use to individuals who do not own them. These services are receiving a wide-spread adoption in major cities around the world, with over 300 active systems and more than 200 in planning. Bike sharing systems provide an affordable alternative to motorized public transport or private vehicles, thereby reducing traffic congestion, noise, and air pollution.

Figure 1: Bike sharing hub in London

There have been three generations of bike-sharing systems over the past 45 years. The first generation began in Amsterdam on July 28, 1965, where simple bikes painted in white (*Witte Fietsen*) were provided for public use. It was not until 1995 that the first large-scale second generation bike-sharing program was launched in Copenhagen as *Bycyklen*, or *City Bikes*. The bikes were specially designed for intense utilitarian use with solid rubber tires and wheels with advertising plates, and could be picked up and returned at specific locations with a coin deposit. Finally, the third and current generation improved customer tracking and offered a variety of technological perks for users, such as online tracking of bike availability. The bike sharing concept was then spread throughout the world: Today, there are hundreds of similar bike sharing programs.

Bike-sharing has had profound effects on creating a larger cycling population, increasing transit use, decreasing greenhouse gases, and improving public health. The system raised bike mode share between 1.0 - 1.5 percent in cities with historically low cycling use. For example, cycle mode share in Barcelona was 0.75 percent in 2005 and increased to 1.76 percent in 2007, the year its bike sharing system, *Bicing* was launched (Romero 2008).

Many bike-sharing programs also take pride in their environmental contribution. Montreal's *Bixi* proudly states that its program has saved over 3,000,000 pounds of greenhouse gases since its inception in May 2009 (Bixi 2009a). Lyon states that its program, which was launched in 2005, has saved the equivalent of 18,600,000 pounds of CO_2 pollution from the atmosphere (Greater Lyon 2009). The public health benefits of bike-sharing have yet to be analyzed, though the health benefits of cycling are well-known and motivates further extensions of the program (Andersen et al. 2000; Cavill and Davis 2006; Shepard 2008).

Figure 2: Superheroes also use bike sharing

How does bike sharing work?

We consider here a *membership type* of bike-sharing systems, as implemented in the city of Toronto. Bicycles are kept at self-service terminals (*stations*) throughout the city, which work 24 hours a day, 365 days a year. Individuals registered with the program identify themselves by a membership key in station kiosk, and take the bikes for a short period of time, usually three hours or less. A bike is typically returned to a station different than the one that it was originally located at.

Figure 3: Bike sharing station in Toronto

The Inventory Rebalancing Problem

In this competition you will tackle a real-world problem faced by the bike sharing system in the city of Toronto, *Bike Share Toronto (BikeTO)*. The stations and bicycles in BikeTO are owned by the local government and operated in a public-private partnership with *Motivate*. With more than 800 bicycles operating from 80 stations, the system is one of the largest bike sharing service in Canada.

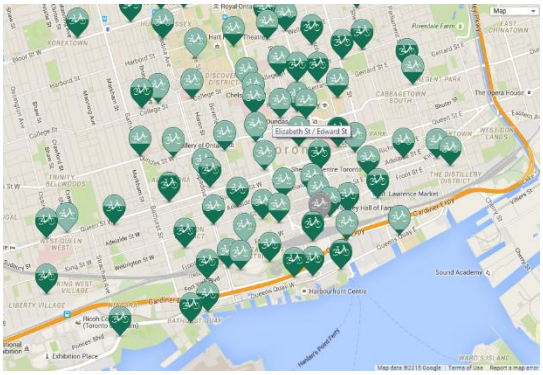
Figure 4: Partial BikTO Station Map in Toronto

BikeTO implements a membership type of bike sharing program. Users can pick up and return bikes at designated stations, each having a limited number of *docks* (that is, places where bikes are positioned inside a station). Unfortunately, user behavior results in spatial imbalance of the bike inventory over time. Stations are often characterized by unacceptably low availability of bikes or open docks, hence limiting pickups and returns, respectively.

For example, imagine what happens at 8 am in the morning: the users will take bicycles at stations located in the suburbs and ride them towards downtown for work or school. As a result, there might be a low availability of bikes in the suburb stations, and not enough space to return the bikes in the downtown stations. At 6 pm in the evening, the scenario inverts: many people will instead take the bikes from stations in downtown to the suburbs, and the same issue occurs.

BikeTO applies the following method to ensure that the number of bikes at each station are adequate at all times. Using inventory management techniques and historical data, BikeTO decides how many bikes should be either added or removed from each station and at which time windows that should happen. Then, trucks are sent to move the bikes from stations with excess inventory to stations with lack of inventory, ensuring the desired levels are satisfied.

The main issue with this method is that, even though the data on the excess or deficiency of bikes was shown to be fairly accurate, the routing component is still quite inefficient. Trucks usually take longer than they should to redistribute the bikes or are unable to return the bikes within the time period, increasing overall costs and harming inventory levels.

Given a set of stations and their respective bike excess or deficiency, your goal is to create a truck routing with minimum cost that ensures all station requirements are met within their time windows. A truck starts from a central depot at time 0, visits each station exactly once to either remove or add bikes to the station docks, and then returns to the central depot. To facilitate operations, a station can only be served by one truck and the time to restock/remove bikes of a station is negligible. Different trucks are available, each having a distinct capacity on the number of bikes they can carry. You are also given a fixed (symmetric) travel time to go from a station to another. The cost of a truck is computed by the total unit of times the truck travels times a *truck cost c*, which can be different for each truck. You can assume that initially a truck carries zero bikes, and that it can bring bikes to be stored at the depot when it returns.

Without loss of generality, each station is associated with a single bike excess or deficiency level, represented by a positive or negative integer, respectively, and a unique time window, which is an interval *[r, d]* with a *release r* and a *deadline d*. If a truck arrives before a release, it can wait close to the station. There is a limited number of trucks available, and not all of them need to be utilized as long as all the bike requirements are met.

For example, suppose we are given an instance with 6 stations depicted as nodes in Figure 5. Stations are identified by numbers 1 to 6, and station 1 is our central depot. Suppose the stations 2 to 6 have bike levels +14, -7, -5, +8, -6, respectively (e.g., station 2 has an excess of 14 bikes). Also, the time windows that each bike excess/deficiency should be addressed are given by the intervals next to each node in Figure 6. The travel times are as follows.

	1	**2**	**3**	**4**	**5**	**6**
1	-	7	17	6	4	7
2		-	8	12	14	16
3			-	3	25	18
4				-	12	15
5					-	6
6						-

Finally, suppose that you have two trucks, A and B. Truck A has a capacity of 20 bikes and a truck cost of 8, while truck B has a capacity of 9 bikes and a truck cost of 6.

The optimal solution to this instance is depicted in Figure 6 with the corresponding arrows. Truck A travels to stations 2, 3, and 4 in order, which yields a total travel time of 24 time units and hence incurs a cost of 192. Truck B travels to stations 5 and 6 in order and incurs a cost of (4+6+7)*6 = 102. Hence, the total cost of this routing is 294, which is optimal to this problem.

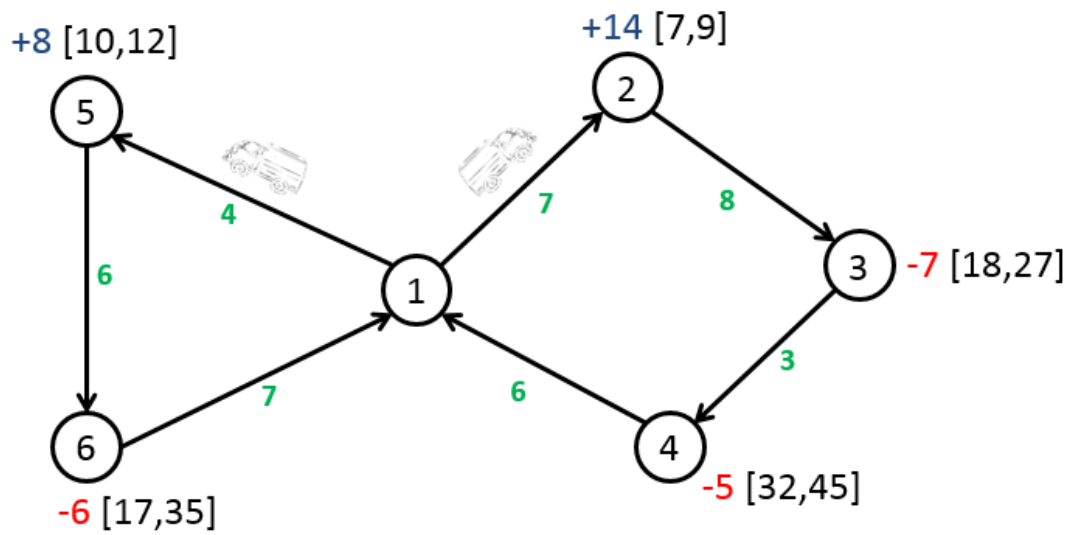

Figure 5: Example of an instance

Input Data

Each instance is given by a text file formatted as follows. **We assume the first station is always the central depot and that distances are symmetric.**

[number of trucks]
[capacity of truck 1] [cost of truck 1]
[capacity of truck 2] [cost of truck 2]
…
[number of stations]
[bike excess/deficiency of station 1] [release of station 1] [deadline of station 1]
[bike excess/deficiency of station 2] [release of station 2] [deadline of station 2]
…
[adjacency matrix of distances]

For example, the instance in the example above is written as follows.

```
2
20 8
9 6
6
0 0 0
14 7 9
-7 18 27
-5 32 45
8 10 12
-6 17 35
0	7	17	6	4	7
7	0	8	12	14	16
17	8	0	3	25	18
6	12	3	0	12	15
4	14	26	12	0	6
7	16	18	15	6	0
```

Submission, Evaluation, and Prizes

Please either submit your source code or your binaries (compiled in any x64 system) by July 11th at midnight (EST). You are allowed to use any language or optimization technology you prefer, as long as it is free for academic use (hint: we recommend any CP solver!). Also include a one-page abstract with a brief summary of your technique.

Your solver should print to the standard output, in order, the index of the trucks used (according to the input) and the sequence of stations visited, including the central depot. Both truck and station indices should start at 1. For instance, in figure 5 the solution is

```
1
1 2 3 4 1
2
1 5 6 1
```

We will run your technique on **3 hidden instances** for 10 minutes on a computer with 16 GB of RAM. Please make sure your approach allows for a time-limit specification. The technique that score the highest number of points (evaluated according to the quality of solutions provded) will be awarded a prize and announced at the ACP meeting during the CP 2015 conference.

To test your code, we have provided 10 instances accessible at **[todo]**. To submit your code or binaries, **todo.**

References and Acknowledgements

- History of bike-sharing system was extracted from *DeMaio, Paul. 2009. Bike-sharing: History, Impacts, Models of Provision, and Future. Journal of Public Transportation 12(4), 41-56,* and on the bike-sharing Wikipedia page, which can be accessed at http://en.wikipedia.org/wiki/Bicycle_sharing_system.
- Pictures were extracted from the *Bike Sharing Blog*, which can be accessed at http://bike-sharing.blogspot.com/.
- Station data in this project was inspired from the one provided by *Capital Bikeshare* in Washington D.C., downloadable at http://*capitalbikeshare.com*.