A Meta-heuristic Approach to Repositioning Bicycles in a Public Bicycle Sharing System

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MOTIVATION

• Rapid growth of Bicycle Sharing Systems (BSSs) all around the world

• BSSs have many benefits such as reducing the congestion and pollution

• Challenges faced by BSSs include system imbalance, theft/vandalism and policy

SYSTEM IMBALANCE PROBLEM

• Imbalanced state of the system:

  This causes dissatisfaction among the users and might also lead to a loss of users and revenue

  It is crucial to the success of the system

  Incentivized Redistribution: Incentives provided to the users for self-balancing distribution of bicycles

  Network Intervention: The operating agency repositions the bicycles using vehicles

    Static Repositioning: Bicycles are repositioned when the system is ‘inactive’

    Dynamic Repositioning: Bicycles are repositioned when the system is ‘active’

    Hybrid Repositioning: A mixed strategy using both static and dynamic repositioning

OBJECTIVES

• Develop optimization models for the static repositioning of bicycles in a BSS to:

  • Ensure the minimum availability of bicycles and empty docks at the stations

  • Minimize the cost of the repositioning operation

STATIC REPOSITIONING

• The operation cost has 3 components: Time cost, Fuel cost and Labor cost

  The static repositioning operation takes place when the system is ‘inactive’ – i.e. when very few users are using the system

  Characteristics:

    • An inexpensive way of doing the repositioning

    • It can handle systems which are not too dynamic

    • Challenges:

      • It cannot be used to quickly respond to unusual changes in the demand

      • It cannot be used in very active systems

MIXED INTEGER LINEAR PROGRAMMING MODEL FOR STATIC REPOSITIONING

Notations:

N: The set of nodes (0,1,...,n)

N*: The set of nodes excluding the depot (1,2,...,n)

V: The set of vehicles (0,1,...,|V|)

δ: The deadline of the repositioning operation

Qk: The capacity of the vehicle k

tij: The travel time between node i and node j

p: The number of bicycles to pick up at node i

qi: The number of bicycles to drop off at node i

s: The service time at node i

xij: Binary variable equal to 1 if arc (i,j) is served by vehicle k and 0 otherwise

xi: The cumulative number of bicycles picked up by vehicle k after visiting node i

xk: The cumulative number of bicycles dropped off by vehicle k after visiting node i

T: The cumulative time spent in the operation by vehicle k after visiting node i

r: The penalty for overtime

o: The overtime for vehicle k

Restricted Static Bicycle Repositioning Model (ResSBRM)

\[
\min \sum_{i,j \in N \times N} t_{ij} x_{ij} \quad \text{The total travel cost} \quad (1)
\]

Subject to

\[
\sum_{i,j \in N \times N} x_{ij} = 1, \forall i \in N, i \neq j
\]

\[
\sum_{j \in N \times N} x_{ij} = 1, \forall i \in N, i \neq j
\]

\[
\sum_{i,j \in N \times N} x_{ik} = x_{kj}, \forall i,j \in N, i \neq j \quad \text{Flow Conservation} \quad (4)
\]

\[
\sum_{i,j \in N \times N} x_{ij} = 1, \forall k \in V
\]

\[
\xi_i = t_i + p_i + (q_i - 1)M, \forall i \in N, i \neq 0
\]

\[
\xi_k = t_k + q_k + (1 - x_k)M, \forall k \in V, \xi_k \geq 0, \xi_k \leq Q_k
\]

\[
\xi_k \geq \xi_{k+1}, \forall k \in V, k \neq 0
\]

\[
T_k \geq t_k + x_k + q_k + (1 - x_k)M, \forall i \in N, i \neq 0
\]

\[
T_k \geq t_k + x_k + q_k + (1 - x_k)M, \forall k \in V, \forall i \in N, i \neq 0
\]

\[
T_o = \sum_{i,j \in N \times N} t_{ij} x_{ij} \quad \text{Time Deadline} \quad (16)
\]

\[
\xi_{ij} \geq 0, \forall i,j \in N, i \neq j
\]

\[
x_{ij} \in \{0,1\}
\]

\[
\xi_{ij}, \xi_{ij} + t_{ij}, T_o = 0, \forall i,j \in N
\]

\[
x_{ij}, \xi_{ij}, t_{ij} \geq 0, \forall i,j \in N, i \neq j
\]

Relaxed Static Bicycle Repositioning Model (RelSBRM)

\[
\min \sum_{i,j \in N \times N} t_{ij} x_{ij} + \sum_{i,j \in N \times N} \alpha x_{ij} \quad \text{The total weighted travel cost} \quad (20)
\]

\[
\alpha \geq 0, \forall i,j \in N
\]

\[
\alpha \geq 0, \forall i,j \in N
\]

\[
\text{Overtime penalty} \quad (21)
\]

\[
\text{Overtime penalty} \quad (22)
\]

Compared to ResSBRM, constraint (16) can be replaced by constraint (21) and constraint (22) is an additional constraint. All the other constraints are the same.

META-HEURISTIC ALGORITHM FOR STATIC REPOSITIONING PROBLEM IN BICYCLE SHARING SYSTEMS

RESEARCH AND DEVELOPMENT

A Meta-heuristic Algorithm

The heuristic algorithm was applied to the Velo Antwerp network

The demand pattern on the weekends is found to be suitable for Static Repositioning

Table 1 Comparison of MILP with Heuristic (Standard Deviations in parentheses)

Table 2 Comparison of Heuristic performance with actual dispatch reports (Standard Deviations in parentheses)

CONCLUSIONS

• The proposed heuristic algorithm is a good way for the static repositioning of bicycles in a BSS with a low activity level

• The comparison of the heuristic and the MILP shows a close gap to the optimal results

• The results show that considerable cost savings can be obtained by using the proposed heuristic algorithm instead of the traditional repositioning methods

REAL WORLD NETWORK APPLICATION AND RESULTS

The total travel cost

Travel Cost

Weighted Travel Cost

Cost savings

Jan 21 2012
929
671
343.7 (10.9)
487
585.3

Mar 17 2012
1067
721
363.3 (12.6)
467
656.7

May 20 2012
833
676
359.3 (10.3)
629
473.3

Jun 24 2012
834
576
350.2 (10.1)
583
483.8

Aug 29 2012
548
44
310.4 (10.4)
459
237.6

Nov 17 2012
605
256.8

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