Problem extension:

e-bike static repositioning problem with stations with limited charging docks (sort of multiple depot problems)

Objective: Minimize penalty cost

Given:

1. One main depot: Infinite many usable bikes & batteries
2. **The number of charging docks at each station (Limited, can be zero)**
3. Number of usable bikes and non-usable bikes for each station
4. Optimal inventory level

and so on

Constraints:

1. Each station can visit at most once

**(How about the capacity of the repositioning vehicle cannot satisfy the station demand by visiting only once?)**

**(How to represent dummy depot in CEPLX)**

and so on

Decision to be make while visiting a station:

1. Number of battery replacement (battery collected at main depot only?)
2. Number of non-usable bikes to collect
3. Number of usable bikes to collect
4. Number of usable bikes to drop off
5. **If charging station, number of non-usable bikes to drop off** 
   1. Given that each station are visited at most once, a non-usable bike become a “charging bike” after putting them to the charger. It is considered to be a usable bike but cannot be collected instantly as a usable bike to repositioning vehicles since it needs time to charge (Let’s call “Charging bike”)

Problem property extension:

1. Effect of the location of main depot? (maybe not)

Possible result:

If the stations is close to the main depot, prefer battery swapping more instead of charging?

1. Effect of the number of charging docks for each stations?
   1. Comparison between the old version and new version? (Charging facility: 0 for all stations)

Old: No charging stations, non-usable bikes can only undergo battery swapping/return to main depot

Possible result:

* + - Penalty cost becomes smaller with the aid of charging facilities
  1. More charging facilities at the stations -> always result in smaller or equal penalty cost?
     + Effectiveness of the charging facilities?
     + Related to the number of non-usable bikes?

(diminishing return)

* 1. More charging facilities at the stations -> solution space increases -> running time increases?

1. Effect of the proportion of non-usable bikes

Possible result:

The higher the percentage of non-usable bikes, the higher the penalty cost?

1. Effect of vehicle capacity

Possible adjustment:

1. The proportion of the capacity for bikes & batteries
   1. what proportion gives optimal results? (Optimal proportion)
   2. How the inputs affect optimal proportion?
2. Clustering?

Problem 1:

If some of the clusters did not contain the main depot, how can the cluster satisfy the demand

Problem 2:

If I use GA/LNS, provide local optimal solution for each cluster -> decrease running time?

**Notations**

Sets

|  |  |
| --- | --- |
|  | Set of stations |
|  | Set of stations and dummy depots |
|  | Set of nodes, including the stations, depots, and dummy depots |
|  | Set of the depot and dummy depots |
|  | Set of vehicles |

Indices

|  |  |
| --- | --- |
|  | Indices of nodes |
|  | Index of vehicle |

Parameters

|  |  |
| --- | --- |
|  | Initial number of usable e-bikes at non-charging docks of station |
|  | Initial number of non-usable e-bikes at non-charging docks of station |
|  | Initial number of usable e-bikes at charging docks of station |
|  | Initial number of non-usable e-bikes at charging docks of station |
|  | Capacity of e-bike non-charging dock capacity of station |
|  | **Capacity of e-bike charging dock capacity of station** |
|  | Vehicle capacity for e-bikes |
|  | Vehicle capacity for batteries |
|  | Repositioning time |
|  | Time required to load an e-bike from a station onto a vehicle (How about to a depot) |
|  | Time required to unload a e-bike from a vehicle to a station (How about to a depot) |
|  | **Time required to unload a non-usable e-bike from a vehicle to a station and plug it into a charging dock** |
|  | Time required to perform a battery swap |
|  | Time required to load a fully charged battery at the depot |
|  | Time required to unload **a battery with an insufficient energy level** at the depot |
|  | A very large number |
|  | Travel time from node to node |
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|  |  |

Decision variables

|  |  |
| --- | --- |
|  | Binary variable that equals one if vehicle travels directly from node to node , otherwise it is equal to zero |
|  | Number of usable e-bikes from non-charging docks loaded onto vehicle at node |
|  | Number of usable e-bikes from charging docks loaded onto vehicle at node |
|  | Number of usable e-bikes unloaded to non-charging docks from vehicle at node |
|  | Number of usable e-bikes unloaded to charging docks from vehicle at node |
|  | Number of non-usable e-bikes at non-charging dock loaded onto vehicle at node |
|  |  |
|  | **Number of non-usable e-bikes unloaded** to charging docks **from vehicle at node and do charging (only for charging stations)** |
|  | Number of battery swaps performed for e-bikes at non-charging docks at node using fully charged batteries from vehicle (i.e., number of fully charged batteries unloaded from vehicle at node ) |
|  | Number of battery swaps performed for e-bikes at charging docks at node using fully charged batteries from vehicle (i.e., number of fully charged batteries unloaded from vehicle at node ) |
|  | Number of non-usable e-bikes unloaded onto vehicle **at depot or dummy depot** |
|  | Number of fully charged batteries loaded onto vehicle at depot or dummy depot |
|  | Number of batteries with insufficient energy level unloaded from vehicle onto depot or dummy depot |
|  |  |
|  |  |

Assumption:

1. No non-usable e-bikes pick-up at charging docks

Auxiliary variable

|  |  |
| --- | --- |
|  | **Number of usable e-bikes on vehicle when it travels directly from node to node** |
|  | **Number of non-usable e-bikes on vehicle when it travels directly from node to node** |
|  | **Number of fully charged batteries on vehicle when it travels directly from node to node** |
|  | **Number of batteries with an insufficient energy level on vehicle when it travels directly from node to node** |
|  | **Auxiliary variable associated with node used for the sub-tour elimination constraints** |
|  | **Number of usable e-bikes at station at the end of the repositioning operation** |
|  | **Number of non-usable e-bikes at station at the end of the repositioning operation** |

Function

|  |  |
| --- | --- |
|  | A convex penalty function for station defined over and |

**Formulation**

|  |  |
| --- | --- |
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| s.t. | (2) |
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|  | (20.0) |
|  | (20.1) |
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|  | (23) |
|  | (24.0) |
|  | (24.1) |
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|  | (32) |
|  | (33) |
|  | (34) |

(1) Objective function: minimize penalty cost

(2)(3): Define the final number of usable bikes and non-usable bikes at each station

(4)(5): The vehicle load difference

(6): All non-usable e-bikes back to depot should be unloaded

(7): No non-usable e-bikes when it leaves depot

(8): All new fully charged battery pick up from the depot/dummy depot

(9): No insufficient energy battery leave from depot/dummy depot

(10): Difference in the number of fully charged battery on the vehicle = Number of battery swap

(11): Difference in the number of insufficient energy battery on the vehicle = Number of battery swap

(12): All insufficient energy battery unload at depot/main depot

(13): No fully charged battery back to depot/main depot

(14)(15): The number of e-bikes and batteries on the vehicle do not exceed the capacity

(18): The usable bikes pick-up quantities cannot larger than usable bikes available at that station

(19.0): The non-usable bikes pick-up quantities cannot larger than non-usable bikes at non-charging docks available at that station

(20.0): The usable bikes drop-off quantities to non-charging docks cannot be larger than the number of available non-charging docks at that station

(20.1): The total bikes drop-off quantities cannot larger than total number of e-bikes at charging docks of that station

(21): All usable bikes pickup should eventually drop off

(22): All fully charged battery picked up from the depot/dummy depot performed swap

(23): The number of battery swap at a station should be smaller than or equal to the number of fully charged batteries on the vehicle

(24.0)(24.1): The number of battery swap at a station should be smaller than or equal to the number of non-usable bikes at that station

(25): The number of fully charged batteries pickup should be smaller than the battery capacity of the vehicle

(26): Restrict the total time

(27): sub-tour elimination constraints (Miller)

(28-34): domain constraints

**Objective function:**

Auxiliary variable

|  |  |
| --- | --- |
|  | Shortage of usable e-bikes for station |
|  | Shortage of available docks for station |
|  | Total e-bike capacity for station |

Parameters

|  |  |
| --- | --- |
|  | Penalty cost for each shortage of usable e-bikes |
|  | Penalty cost for each shortage of available docks |
|  | Targeted inventory level of usable e-bikes for station |
|  | Targeted number of available docks for station |

The objective function in (1.1) is to minimize the sum of total penalty cost for all stations. The total penalty cost of a station is represented by a weighted penalty cost sum of: (i) shortage of usable e-bikes, and; (ii) shortage of docks.

Equation (1.2) and (1.3) defines the shortage of usable e-bikes and shortage of available docks for a station.

The shortage of usable e-bikes of a station is non-negative if and only if the targeted inventory level of usable e-bikes of that station is greater than or equal to the number of usable e-bikes of that station at the end of the repositioning operations.

The shortage of available docks of a station is non-negative if and only if the total number of usable and non-usable e-bikes of that station at the end of the repositioning operations is greater than or equal to the difference between the total e-bike capacity of that station.

|  |  |
| --- | --- |
|  | (1.1) |
|  | (1.2) |
|  | (1.3) |
|  | (1.4) |