MeHUB: Integrating a Connected Micromobility Infrastructure to the Existing Public Transport

MeHUB project aims at consolidating the electric-powered shared micromobility vehicles such as e-scooters and e-bikes into hubs in order to manage their charging and maintenance operations efficiently. Therefore, determining the locations of these e-hubs and the required charging infrastructure is of paramount importance for satisfying the needs of the commuters. We address this problem using an optimization approach and develop a model for siting and sizing micromobility e-hubs within an urban context.

In MeHUB, we deal with finding the optimal sites to build the e-hubs and determining the quantity of charging units at each site to maximize the utilization of the fleet. We first define the notation employed in the optimization model, present the formulation and describe it. Then, we implement it to determine e-hub locations using the commuter data provided by the AMM transport authorities. The data includes home and work locations of 120 citizens selected for the pilot implementation. An optimization solver was employed to solve the formulated mathematical model based on the criteria and parameters set by the AMM authorities. According to the optimal solution obtained, six metro stations were selected as e-hub locations and 58 chargers were distributed optimally to these e-hubs according to the expected demand of potential e-bike users. In addition, two chargers were installed at the "Bicycle Campus" of AMM for testing a non-metro station e-hub. Ride data had been collected for a period of two weeks to investigate the commuter behaviour and effectiveness of the selected locations. The results were promising despite the unfavourable winter conditions and supported the e-hub location decisions; however, the collected data reveals that some charging units may be repositioned to enhance the service levels.

Model Formulation

The mathematical notation employed in the formulation of the e-hub location problem is as follows:

**Sets:**

- $V$: Set of all commuters
- $S$: Set of metro stations

**Parameters:**

- $d_{ij}$: Distance between commuter $i \in V$ and commuter $j \in V$
- $D_{\text{max}}$: Maximum distance between a commuter and hub
- $a_{ij}$: Binary (0-1) coverage parameter (i.e. $a_{ij} = 1$ if $d_{ij} \leq D_{\text{max}}$)
- $b_{sj}$: Binary (0-1) parameter represent that the metro station $s \in S$ is the nearest station to commuter hub $j \in V$
- $P_h$: Maximum number of hubs in districts
- $P_e$: Maximum number of e-hubs in metro stations
Maximum number of chargers in an e-hub
Number of total commuters per charger installed
Maximum number of total available chargers
A sufficiently small constant

Decision variables:
\( x_j \) 1 if a commuter hub is located at commuter \( j \in V \); 0 otherwise
\( z_i \) 1 if commuter \( i \in V \) is covered; 0 otherwise
\( w_s \) 1 if an e-hub is located in metro station \( s \in S \); 0 otherwise
\( q_s \) Number of chargers in metro station \( s \in S \)
\( y_{ij} \) 1 if commuter \( i \in V \) is assigned to hub \( j \in V \); 0 otherwise
\( T \) Maximum walking distance between a commuter and a hub

The mathematical programming (mixed integer linear programming) model can be formulated as follows:

\[
\max \sum_{i \in V} z_i - \epsilon \sum_{s \in V} q_s \tag{1}
\]

subject to:
\[
\sum_{j \in V} a_{ij} x_j \geq z_i \quad i \in V \tag{2}
\]
\[
\sum_{j \in V} y_{ij} \leq z_i \quad i \in V \tag{3}
\]
\[
y_{ij} \leq x_j \quad i, j \in V \tag{4}
\]
\[
w_s \geq b_{sj} x_j \quad j \in V, s \in S \tag{5}
\]
\[
T \geq \sum_{j \in V} d_{ij} y_{ij} \quad i \in V \tag{6}
\]
\[
\sum_{j \in V} x_j \leq P_h \tag{7}
\]
\[
\sum_s w_s \leq P_e \tag{8}
\]
\[
\sum_{i \in V, j \in V} b_{sj} y_{ij} \leq K \times q_s \quad s \in S \tag{9}
\]
\[
w_s \leq q_s \leq P_s \quad s \in S \tag{10}
\]
\[
\sum_{s \in S} q_s \leq Q \tag{11}
\]
\[
x_i, z_i \in \{0,1\} \quad i \in V \tag{12}
\]
\[
y_{ij} \in \{0,1\} \quad i, j \in V \tag{13}
\]

The objective function (1) maximizes the total number of covered commuters. Constraints (2) is a covering constraint that makes sure the commuter \( i \) will be covered by commuter \( j \) if \( a_{ij} = 1 \). Constraints (3) guarantee that if commuter \( i \) is assigned to commuter \( j \), then the commuter \( i \) must be covered.
Constraints (4) make sure that if commuter \(i\) is assigned to commuter \(j\), then commuter \(j\) will be a commuter hub. Constraints (5) show that if a commuter hub is located at commuter \(j \in V\), then an eHub must be located in commuter \(j \in V\) nearest metro station \(s \in S\). Constraints (6) satisfy the maximum walking distance between a commuter and a hub. Constraints (7) and (8) control the maximum number of hubs in districts and the maximum number of e-hubs in metro stations, respectively. Constraints (9) guarantee that if commuter \(i \in V\) is assigned to hub \(j \in V\), then at most \(K\) chargers can be installed in metro station \(s \in S\). Constraints (10) show that if an e-hub is located in a metro station \(s \in S\), at least one charger must be installed in the associated metro station. Constraints (11) provide the upper bound on a maximum number of total available chargers. Finally, constraints (12)-(13) define the domain of the binary decision variables.

**Implementation and Results**

The field trials were performed during three weeks spanning the end of January and beginning February 2022 and ride data were collected from seven e-hubs given in Table 1.

<table>
<thead>
<tr>
<th>E-Hub Location</th>
<th>Abbr.</th>
<th>No. of Chargers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bahçelievler Metro Station</td>
<td>BAH</td>
<td>12</td>
</tr>
<tr>
<td>Batı Kent Metro Station</td>
<td>BAT</td>
<td>8</td>
</tr>
<tr>
<td>Bilkent Metro Station</td>
<td>BIL</td>
<td>14</td>
</tr>
<tr>
<td>Bicycle Campus</td>
<td>BIS</td>
<td>2</td>
</tr>
<tr>
<td>Kızılay Metro Station</td>
<td>KIZ</td>
<td>8</td>
</tr>
<tr>
<td>Korus Metro Station</td>
<td>KOR</td>
<td>8</td>
</tr>
<tr>
<td>National Library Metro Station</td>
<td>MIL</td>
<td>8</td>
</tr>
</tbody>
</table>

An interruption during five consecutive days had occurred because of harsh weather conditions and below 0 °C ambient temperature levels. Therefore, the data belongs to net two weeks. 45 users performed a total 230 rides using the magnetic cards provided. We excluded the rides with a duration of than one minute assuming they do not correspond to actual micromobility trips. The data is summarized in Table 2.

<table>
<thead>
<tr>
<th>From:</th>
<th>BAH</th>
<th>BAT</th>
<th>BIL</th>
<th>BIS</th>
<th>KIZ</th>
<th>KOR</th>
<th>MIL</th>
<th>Total</th>
<th>Attempts</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAH</td>
<td>19</td>
<td>20</td>
<td>2</td>
<td>5</td>
<td>3</td>
<td>8</td>
<td>8</td>
<td>32</td>
<td>61</td>
</tr>
<tr>
<td>BAT</td>
<td>20</td>
<td>4</td>
<td>14</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>25</td>
<td>61</td>
<td>8</td>
</tr>
<tr>
<td>BIL</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td>25</td>
<td>61</td>
<td>8</td>
</tr>
<tr>
<td>BIS</td>
<td>5</td>
<td>23</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>25</td>
<td>61</td>
<td>20</td>
</tr>
<tr>
<td>KIZ</td>
<td>3</td>
<td>1</td>
<td>32</td>
<td>2</td>
<td>7</td>
<td>48</td>
<td>48</td>
<td>114</td>
<td>114</td>
</tr>
<tr>
<td>KOR</td>
<td>7</td>
<td>1</td>
<td>1</td>
<td>17</td>
<td>26</td>
<td>24</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MIL</td>
<td>8</td>
<td>2</td>
<td>3</td>
<td>10</td>
<td>16</td>
<td>39</td>
<td>230</td>
<td>271</td>
<td></td>
</tr>
</tbody>
</table>

Total 32 25 24 36 51 25 37 230 271

* Excluding trips < 1 min
From the collected data we observe that almost 40% of the trips correspond to Kızılay metro station and Bicycle Campus, whereas only 17% (ten out of 60) chargers were installed in those two e-hubs. Although the trials took place with only 25 e-bikes, the ride data points out a need for repositioning existing chargers and/or installing additional chargers at Kızılay metro station, which is located at the heart of Ankara city center, and also at Bicycle Campus, which is a major attraction point for bike commuters. On the other hand, the data shows that the demand at Bahçelievler and Bilkent metro stations were overestimated as 43% of the charging units were installed at these two locations while 25% of the rides took place.

The last column in Table 2 reports the numbers of attempts for unlocking the e-bikes using unidentified magnetic cards, AMM public transportation cards in general. This data shows the interest of the citizens towards this new e-bike sharing system, with 42% occurring in Kızılay, a major business and entertainment district.

The collected ride data is also visualized in Figure 1. In this figure, the sizes of the circles representing the e-hubs and the widths of the connecting arcs are proportional to the number of trips.

![Figure 1. Ride volumes](image)

Conclusions

The pilot trials took place in a short time frame and under unfavourable weather conditions that had adversely affected the utilization of the e-bikes. More meaningful and insightful data could have been collected in warm and mild conditions. The collected data support the location decisions. Installation of e-hubs close to metro stations and at Bicycle Campus provided visibility to both users and citizens, and promoted the utilization of e-bikes as an alternative transportation mode to metro as well as public road transport. On the other hand, the sizing decisions, i.e. determining the number of charging units at each location, may be revised to enhance the employment of the bike sharing system.