I. Introduction

This paper provides a methodology that aids route configuration in transit design by authoring a k-th shortest path search model in a Logos application. The objective is to generate a network of direct, time-efficient, operator cost-efficient routes for sample cities with known transportation demand, using Netlogo. The methodology consists of three phases: (1) network representation of the sample city; (2) a combined execution of Dijkstra’s and K-th Shortest Path algorithms to generate candidate routes and a user-centered interface design with Netlogo; and (3) the selection of the optimal route set based on minimal operator costs. The constraints include minimum and maximum route lengths, route size (number of routes). Transit service speed and commuter speed are assumed constant; hence, congestion effects are not considered. Demand is assumed to be fixed and representative of the total potential demand for public transport. The novelty in this study is mainly from the second phase of the methodology, where a set of k-th shortest paths is searched for the first time in a Logos application, which provides an interactive tool allowing the network designer to visualize the proposed solution and construct new solutions if input or constraints are changed.

The methodology is tested using a bus network problem in Obihiro city. There are twenty-eight zones covered by the 2006 Person-Trip Survey; twenty-two are within the service coverage of bus service operators. For a potential passenger size of 171,153, there are 151 active bus units traversing 24 routes. The author is deeply familiar with OD-based measures for restructuring the city’s bus network. Car dependency is very high for a population with 60% of its drivers already over 65 years of age[2]. Rising energy costs and falling revenues compel local governments to subsidize operations. Meanwhile, the existing route network remains unresponsive to mobility needs; hence, the urgency for route reconstruction.

II. Methodology

2.1. Network Representation

In representing traffic zones, we use a grid of nodes and links that denote origin and destination (OD) points, actual road intersections, and links that connect ODs to the real road network. Centroid zones represent origin and destination (OD) points of commuters. Each centroid node is connected the real road network by fictitious distribution links. These imaginary distribution nodes and links are used so that the shortest path algorithms can be carried out in the network. The real road network is denoted by intersection nodes and links. Figure 1 illustrates a typical traffic zone in a network.

From route maps provided by the Obihiro Area General Urban Transportation System Investigation (Masterplan Development Investigation) in 2006, we construct a network of nodes and links for our sample city (see figure 2).

2.2. K-th Shortest Path (KSP) Algorithm in Netlogo

According to Fan, W. and Machemehl, R. [5], the KSP process begins with a standard shortest path algorithm by Dijkstra and an iterative procedure that stores results in a set after every other node in the shortest path (except the
destination node) is selected to cut the next shortest path in two segments. The first segment is the path from the source node to the current selected node in the shortest path. The second segment is obtained from a second search for another shortest path originating from the current node and terminating at the destination node.

In this study, we determine the extent to which Netlogo can be used in transportation engineering, in route configuration in particular. Its application in the transit routing problem is a first and the author is highly interested in exploring Netlogo’s convenience in analyzing networks that develop over time in the context of dynamic transit networks. The execution of the KSP search is summarized below.

*********************************************************
; declare variables
turtles-own [node-id L T prev-node Enabled]
links-own [weight]
globals [links-list nodes node-labels set_Bg centroid-list]
; construct network bed
to setup
  clear-all
  set nodes
  set links-list
  set centroid-list
end
to layout
  to set up network of nodes
  let delta_x world-width / x
  let delta_y world-height / y
end
; set up weighted links created in links-list
apply djikstra algorithm and return list of path nodes
to-report get-shortest-path [source_node destination_node]
apply djikstra algorithm and return list of path nodes
end
to-report k-shortest-path [ kMax src dest ]
; obtain k-shortest path [ kMax src dest ]
; ask if node in question is a centroid node
; to store in solution set
set root_path select-shortest-path set_B
set set_B remove root_path set_B
set set_A input root_path set_A
; to output results, set k o while [ k <= kMax ]
output-type "k: "; do for k, nodes, weight
output-print k
set k k + 1
report item kMax set_A
end
; output-print get-total-weight, path_nodes
*********************************************************

2.3. Demand Matrix

Zones with dense trip distribution are highlighted in the OD matrix (table 1). There is a noticeable concentration of movement in within [0602, 0506, 0601, 0702, 0701] and across certain zones [between 0601-0602 and 0701-0702], and little activity in the Central Business District [zone 0101, 0102] where all current routes terminate. The number of OD pairs conforming to these patterns pre-determines the minimum route size (number of routes) we are expected to make.

2.4. Operator Cost

The second optimizer employed in this routing technique is the minimization of operator costs. This is a key measure of network efficiency that compensates for route efficiency achieved by selecting all the shortest paths. It is a variation of travel time, excluding access and egress time. Of the candidate routes for every OD pair, the least costly route is selected as the best route. The unit cost of operation is set at 243 yen per transit unit per hour [2]. W. Fan and R. B. Machemehl’s [5] formulation for operator costs is used.

Objective Function:

\[ \text{Minimize } C_{op} = O_v \times \sum_{r} \frac{C_v \times T_{r}}{hr_{r}} \]

where
- \( C_v \) = hourly operating cost of a bus (243 yen/vehicle/hour)
- \( O_v \) = operating hours for the bus running on any route (hours)
- \( r_m \) = the m-th route of the proposed solution \( (m = 1, 2, \ldots, M) \)
- \( T_{r_m} \) = the round trip time of route \( r_m \)
- \( Dr_{m} \) = total bus route length
- \( V_{a} \) = ave. speed of transit unit (18 kph)
- \( hr_{m} \) = bus headway operating on route \( r_m \);

Subject to:
- \( \sum_{r} Dr_{r} \leq Dr_{m} \geq Dr_{max} \) [Dmax = 11.00 km; Dmin = 3.00 km]
- \( hr_{min} \leq hr_{r} \geq hr_{max} \) [hmin = 900 s; hmax = 1800 s]

III. Results and Discussion

3.1. Proposed Route Network

What results from this routing scheme is then compared with the total operating cost of the existing route network. As this route network was not generated via Logos, the author was compelled to retrace the existing routes on the CAD-generated map to determine the equivalent total path weight and use the unit cost for operation to determine the equivalent operator cost for each route. Table 2 summarizes the equivalent node series for the existing route network (of 24 active routes).

As shown in figures 3 & 4, in the existing network, all the routes meet at the central station. There is one route circulating the city periphery and the rest of the
Table 1. OD Matrix for Obihiro City

| Table 3. Comparison with Equivalent Cost for Current Network |

<table>
<thead>
<tr>
<th>Network</th>
<th>hr</th>
<th>N=T/h</th>
<th>Co/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>NEW</td>
<td>0.16</td>
<td>0.26</td>
<td>¥1,632,452.38</td>
</tr>
<tr>
<td>CURRENT</td>
<td>0.20</td>
<td>0.30</td>
<td>¥2,002,097.37</td>
</tr>
<tr>
<td>Savings</td>
<td></td>
<td></td>
<td>¥369,644.99</td>
</tr>
</tbody>
</table>

Table 2. Tabulated Representation of Proposed Network

routes spread in all 28 zones and converge at the JR station. In the new route set, however, only 2 routes traverse the central station.

All other routes are diffused in the surrounding zones. There are 9 routes circling zones, the rest of the zones cross other zones. Centroid nodes 98, 215 and 282 are not traversed by any route, explaining a large portion of the OD matrix where demand is less than one percent of the highest trip volume observed.

3.2. Cost Comparison with Current Network

By tracing the equivalent node series and the corresponding link weights for the routes in the current network, the total route cost was calculated to reach over 2 million yen, for every 16-hour daily operation of all 24 active routes, using the maximum 30-minute headway. Using the route network generated by selecting the least costly path in a set of K-th shortest paths resulting from a Logos application, we estimate 1,632,452.38 yen, for every 16-hour daily operation of 22 proposed routes, using the same headway. In both cases, the same transit service speed was used vis-à-vis equivalent intersection link weights to determine operator cost.

In comparing the total operator costs of the existing route network and the proposed route network, we find a difference of 369,644.99 yen, per day for all 151 bus units in Obihiro city.
IV. Conclusion and Recommendation

The resulting route network illustrates that direct, k-th shortest, cost-efficient routes do not necessarily have to traverse or terminate at the central station. This suggests that for Obihiro city in particular, or for any other city with known transportation demand, route selection must not be based on service expansion, via random route searches, but on redistributing services to zones with greater potential demand. Hence the KSP search among meaningful OD pairs. This is precisely the case for routing techniques that use automatic procedures that are heavily guided by relevant data. Routes between meaningless OD pairs are excluded from the solution set, shortest path searches are restricted to centroid zones, and the four conditions are met: service coverage, route directness, route efficiency, and network efficiency expressed in operator costs.

The equivalent savings reveal a difference of 369,644.99 yen for every 16-hour daily operation of 22 active routes with an average headway of 30 minutes. Everything else held constant, it can be concluded that using the Logos application to qualify a set of k-th shortest paths between meaningful OD pairs, the proposed scheme for route configuration provides a more cost-efficient set of direct routes for the sample city.

The author recommends that further studies be made to exploit the computing capacity of Netlogo so that cost-efficiency can be jointly performed. It is also recommended that improvements be made in the creation of looping routes and the authoring of models for cases where congestion effects are considered or demand is not fixed.

IV. Conclusion and Recommendation


