Demand-Sensitive Candidate Route Generation Algorithm (DSCRGA)

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ABSTRACT

Demand satisfaction is a key component that reflects the quality of public transit from passengers’ perspective. On the other hand, cost minimization is considered a main objective of transit agencies. This trade-off between quality and cost turns transit network design into a multi-objective problem where passengers’ and operator’s interests conflict. Transit network design involves the determination of various design elements such as route alignments and stop locations which are essential to serve transit demand within a particular area. The design of a transit network typically starts with generating a set of potential routes using a candidate route generation algorithm. Existing route generation algorithms find the shortest path between route’s origin and destination where demand is aggregated, without giving proper attention to the pattern and distribution of demand along the generated route. Given that demand is actually scattered along the transit route, the aggregate demand assumption is considered a major drawback of existing route generation algorithms. In an attempt to fill the highlighted gap in current practice, this paper presents a Demand-Sensitive Candidate Route Generation Algorithm (DSCRGA) that is capable to address passengers’ and operator’s needs in a simple objective function aiming to realize the maximum route-level ridership. The proposed approach is well suited for small and rural communities and specialized transit services (e.g. flex-route and demand responsive services) where transit demand is dispersed.
INTRODUCTION

Public transit is a generic term involving a large family of conventional and innovative technologies complementing each other to provide high capacity, energy efficient, and low emissions movement of people in major metropolitan areas as well as Small and Rural Communities (SRCs). However, the accelerating urban growth and continuing need for mobility are placing more demands on transit systems and reducing the competitiveness of transit as alternative to automobile use (1, 2). As such, modern transit systems must evolve to respond to these challenges and contribute to a vibrant society, strong economy, and healthy environment.

Unlike automobiles, public transit affects the social viability of metropolises by ensuring a travel alternative for choice users and an essential service for captive riders. Further, public transit supports the economic viability of metropolitan areas by enhancing the accessibility to major trip generators and Central Business Districts (CBD) where a mixed variety of activities are located. Public transit also affects the environmental viability of metropolises by limiting the adverse effects of urban sprawl, traffic congestion, and emissions (3). While the benefits of public transit are well known in metropolises, where traffic congestion and emissions are major issues, little is reported on the importance of transit in SRCs.

In Canada, there are over 300 SRCs with populations of less than 50,000 people, representing 15% of Canada’s population. Transit systems serving SRCs represent a significant proportion of the Canadian Urban Transit Association (CUTA)’s operating members. In specific, there are 36 conventional transit systems and 13 specialized transit systems for people with disabilities that serve areas with fewer than 50,000 people (4). According to CUTA’s Transit Vision 2040, the annual transit ridership growth in Canadian SRCs is expected to double by 2040 (5).

The availability of public transit in SRCs can support local businesses, boost local economy, and provide access to jobs and mobility to residents. Nevertheless, the travel needs and characteristics of SRCs present substantial challenges to the development of transit services compared to those of major metropolitan areas. SRCs tend to have low population densities, dispersed land use, scarce transit demand, high auto ownership, rapidly aging population, and limited financial capacity, which require more flexible and innovative transit solutions (6). Moreover, transit planning in SRCs depends largely on the experience of the planner aided with a set of service standards and practical guidelines that specify the minimum acceptable level-of-service. Typically, a number of design scenarios are generated and examined based on different combinations of design elements in order to select the best alternative. Such approach is criticized for yielding suboptimal designs, particularly in terms of maintaining acceptable levels of ridership.

This paper proposes a demand-sensitive approach to transit route design that satisfies the needs of both passengers and operators by maximizing service accessibility at the route-level while minimizing operating cost. The proposed approach is well suited for SRCs and specialized transit services (e.g. flex-route and demand responsive services) where transit demand is dispersed.

The remainder of this paper is arranged as follows: Section 2 reviews the literature on the transit network design problem. Section 3 gives an overview of the proposed approach. Section 4
discusses the model formulation. Section 5 provides an illustrative example. Finally, conclusions are presented in Section 6.

**LITERATURE REVIEW**

Transit planning involves three stages, namely, strategic planning, tactical planning, and operational planning. First, strategic planning mainly deals with transit network design in which various design elements such as route alignment (i.e. spatial layout of route) and stop locations are defined. Second, tactical planning involves frequency setting and timetabling. Finally, operational planning includes transit unit scheduling and crew scheduling (7). Within the first two stages, all information needed by passengers is determined. Treating all these stages simultaneously ensures the interaction and feedback between them. However, this treatment is intractable in practice due to the complexity of the process and the requirement for high computational effort. As a result, numerous approaches have been proposed to deal with sub-problems of transit planning in a sequential manner (8).

Early research has focused on the application of operations research and exact search methods (e.g. linear programming) to model and solve sub-problems of transit planning. Instead of determining the route structure and design parameters simultaneously, analytical optimization models were applied to determine a few design parameters in sequence on a predetermined transit route structure (9, 10). Using continuum approximations and methods of calculus, (10) determined optimal spacing of bus stops along a local bus route with nonuniform many to many travel demand. Further, (9) applied a discrete approach to determine the optimal bus stop locations considering walking time, riding time, and operating cost. Although the small tested instances permitted the models to attain optimality, such models were not applicable to larger realistic networks. Thus, transit planners deem optimal design methods as overly theoretical and lacking simplicity, flexibility, and practical realism. As such, research has been directed towards developing heuristic and evolutionary approaches to find operationally acceptable designs, although global optimality was no longer guaranteed (11, 12). Using a heuristic, (11) designed a “good” route network that minimizes the number of active buses by uncoupling and separately treating route design, frequency setting, timetabling, and bus scheduling. Furthermore, (12) proposed a two-stage heuristic to define a transit network given an empty route network and a constant frequency on all routes. Recently, the interest in biologically motivated approaches such (e.g. artificial neural networks, genetic algorithms, etc.) for solving the transit route design problem has increased. For example, (13) solved the route network design problem by generating a set of candidate routes before selecting the optimum set using genetic algorithms. In general, heuristics and biologically motivated approaches have shown better efficiency and less computational effort than exact search methods, especially with more complex transit networks, with no guarantee of global optimality.

Transit network design, a main element of strategic planning, is the process of determining transit route(s) consisting of two terminals and a sequence of intermediate stops (i.e. route structure), and associated with various design parameters (e.g. route spacing, route length, stop spacing, headway, etc.) which reflect the system performance and resource limitations to serve the demand within a particular area, as shown in Figure 1. A primary data requirement for transit network design is route(s) topology which can be defined by the road network and the potential locations of transit stops, terminals, depots and transfer zones. In addition, the origin-destination (O-D) trip matrix is required to represent the level of demand that needs to be served (7, 8).
Generating a candidate route is critical to transit network design as it affects both frequency setting and bus and crew scheduling, and eventually the overall service quality. Moreover, it is expected that operators will not have the flexibility to alter the routes once operated. Over the years, numerous heuristic approaches were developed to deal with candidate route generation. Such approaches are typically based on shortest path calculations to generate routes subject to some constraints (3). (14) used a link addition approach to generate candidate routes that satisfy length constraints relative to the shortest path. (15) used a node addition approach to generate straight routes with adequate passenger loads. (13) developed a Candidate Route Generation Algorithm (CRGA) to generate transit routes guided by a fixed demand matrix and a set of constraints. The CRGA is a heuristic design algorithm that starts by selecting route origins and destinations from a set of terminal nodes where demand is aggregated. Given the road network in addition to the potential locations of route terminals, a shortest path algorithm (e.g. Dijkstra’s node-labelling, k-Shortest Path, etc.) is used to generate candidate transit route alignments for every terminal node pair. Travel impedance in terms of either distance or time is used as a cost for traversing the route. However, travel time is preferred as a cost of travel as it accounts for traffic congestion. Each of the candidate routes is then checked and filtered with respect to operational and feasibility constraints to ensure keeping them within certain bounds such that, too short and too long routes are discarded so as to reduce the operating costs. Trip directness in terms of route’s deviation from the linear path can also be checked by comparing the additional distance incurred by a transit trip to the same trip by car or other means of travel. Finally, routes that pass the checks are accepted as candidate routes and identified by IDs then ranked based on a performance index and stored in a candidate route set. More recently, (16) presented an iterative approach to solve the transit network design problem with variable transit demand. The presented approach included a mode split model to estimate transit demand and generate an optimal transit network from an initial network based on shortest in-vehicle travel time calculations.

It is clear that generating a transit route based on shortest path calculations ensures trip directness for the passengers and minimum operational cost for the operator. However, a major drawback of the previous transit route generation approaches is the fixed aggregate demand assumption. Most of the previous approaches dealt with single point demand such that potential transit demand was aggregated in the centroids of zones or in other distribution nodes and presented in a fixed demand O-D matrix. Although the issue of fixed demand was tackled by (16), the presented methodology still suffered from the spatial aggregation of demand, meaning that it failed to realize that trips are point-to-point not zone-to-zone. Given that transit demand is
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actually scattered along the transit network, the single point demand assumption does not ensure maximum route-level accessibility. This problem is more pronounced in SRCs where demand is scarce and more flexible transit services are required to meet the full range of mobility needs of the community.

Figure 2 depicts two possible options for transit service at the community level given the same transit fleet. The first option is a ridership model where the high-density areas of the community get frequent service and the low-density areas get no service. The second option is a coverage model where all residents have transit service but at a lower frequency.

![Figure 2. Transit Ridership Model (Left) vs. Coverage Model (Right)](image)

Comparing these two extremes illustrates the transit planner’s dilemma – how to balance the need to provide service that is accessible (i.e. maximize route-level accessibility) and competitive (e.g. minimize travel time, maximize frequency, etc.) to potential riders while keeping operating cost at minimum (i.e. using reasonable service standards). This trade-off between service quality and cost turns the transit planning process into a multi-objective problem where passengers’ and operator’s interests conflict (3). Shortest path-based route generation approaches (e.g. CRGA) can help transit planners design a transit route in a ridership model but will fail to offer a route design in a coverage model. Therefore, a demand-sensitive route design tool that suits the context of SRCs and specialized transit services such as flex-route services and Demand Responsive Transit (DRT), where transit demand is dispersed, is more desirable.

A demand-sensitive transit route design requires rigorous, realistic, and easily computed measures of individual accessibility (17). In general, accessibility is defined as one’s ability to move across space with an implicit temporal significance. Another definition of accessibility is the ease of reaching the desired activities and thus it reflects characteristics of both the land use system where activities are located and the transit system which links the locations of those activities (18, 19).

Access is discussed as a critical accessibility consideration in the strategic levels of transit planning. Access can be defined as the process associated with getting to and departing from the service and hence it represents a major component of the total transit trip travel time (19). Such
access is typically perceived in spatial terms as the physical proximity to transit service. So, an access consideration in the potential use of public transit is the travel distance or time from/to one's origin/destination to/from the transit service. Access greatly impacts the attractiveness of public transit and complements the overall service accessibility. So, if the distance to access a transit service is too long at either trip origin or destination, then the service is unlikely to be utilized as a mode of travel. Hence, approaches designed to support the strategic analysis of transit accessibility must therefore address the issue of access.

In fact, access to public transit is the opportunity to use the service and thus, generating a route alignment that insures suitable access to the service is a desirable objective that affects route-level ridership. Physical access to a transit service is typically achieved by walking, riding a bicycle or taking a car for a short distance. Given an average walking speed of about 1.3 m/s, 5 min walk is often considered a reasonable access threshold in planning for the provision of bus-based transit services. Viewed in terms of physical distance, a suitable access standard in urban areas is typically stipulated 400 meters (19).

Considering the demand distribution in transit route design requires the integration of both spatial and attribute data. Hence, the demand-sensitive route design problem poses a considerable research challenge. Luckily, analysis based on spatial and attribute characteristics is ideally suited to be performed using Geographic Information Systems (20, 21).

DEMAND-SENSITIVE CANDIDATE ROUTE GENERATION ALGORITHM
This section presents a demand-sensitive candidate route generation algorithm for optimal transit route alignment. The proposed approach accounts for the distribution of transit demand along the generated route and aims to minimize the difference between route’s operating cost and revenue. For a transit route serving demand between two terminals and a sequence of intermediate stops, the following objective function is used to address the needs of both passengers and the operator at the route-level:

\[ \mu = C - R, \]

where, \( \mu \) represents the difference between the operating cost of the transit route in dollars per hour (C) and the revenue of the transit route in dollars per hour (R).

i. Operating Cost (C):
According to (2), the operating cost of the transit route can be calculated as follows:

\[ C = \gamma_o N = \gamma_o \left[ \frac{T}{h} \right], \]

where:
\( C \) : operating cost of the transit route per hour ($/h)
\( \gamma_o \) : operating cost per vehicle hour of operation, including costs of drivers, fuel, etc. ($/veh-h)
\( N \) : fleet size required to operate the route
\( T \) : unadjusted cycle time (min)
\( h \) : headway (min)
The unadjusted cycle time (round trip travel time, including layovers at both terminals) can be calculated as follows:

\[ T = \sum_{l=1}^{L} tt_l + ty, \]

where:
- \( T \): cycle time (min)
- \( tt_l \): travel time on link \( l \), including running (\( tr_l \)) and dwell (\( td_l \)) times (min)
- \( ty \): layover required (not including dwell time) at both terminals (min)

As shown in Figure 3, travel time on link \( l \) (\( tt_l \)) is composed of two components: running time on link \( l \) (\( tr_l \)) and dwell time on link \( l \) (\( td_l \)). The running time is the time for a transit unit to start travel from one stop until it stops at the next stop, whereas the dwell time is the time spent by a transit unit at stops for boarding and alighting. By assuming that dwell time at each stop (\( ts_l \)) is split evenly among the two adjacent links, the dwell time on link \( l \) (\( td_l \)) can be calculated as follows: \( td_l = 0.5 \times ts_{\text{left}} + 0.5 \times ts_{\text{right}} \). As such, link travel time can be estimated according to the following equation:

\[ tt_l = tr_l + td_l. \]

On the other hand, total layover at both terminals can be calculated as follows:

\[ ty = ty' + ty''. \]

Figure 3. Cycle Time Components

Layover (terminal time) is the time a transit unit spends at route terminals (not including dwell time). The minimum layover required can be represented by the following equation:

\[ ty = \max(t_w + t_\sigma). \]

where:
- \( ty \): minimum total layover required (not including dwell time) at both terminals (min)
- \( t_w \): layover required for drivers’ work breaks
- \( t_\sigma \): layover required for schedule adjustment and delay recovery
ii. Revenue (R):

The revenue of the transit route can be calculated according to the following equation:

\[ R = \gamma_f \times D, \]

where:

- \( R \): revenue of the transit route per hour ($/h)
- \( \gamma_f \): transit fare per boarding ($/boarding)
- \( D \): hourly route ridership (boarding/h)

Both the route’s operating cost and revenue per hour are calculated at the link-level before assigning the difference \((c_l - r_l)\) to each link as travel impedance. In addition, while per-link layover required for drivers’ work breaks \( (t_w) \) is constant for all links, the per-link layover required for schedule adjustment and delay recovery \( (t_o) \) is affected by route alignment and traffic conditions. To account for such variability, the per-link layover required is estimated as a percentage of the link travel time. This implies that longer links will contribute more to the required layover.

iii. Link-level Operating Cost (\( c_l \)):

\[ c_l = \gamma_o \left[ \frac{\delta \times tt_l}{h} \right], \]

where:

- \( c_l \): operating cost of link \( l \) per hour ($/h)
- \( \gamma_o \): operating cost per vehicle hour of operation, including costs of drivers, fuel, etc. ($/veh-h)
- \( \delta \): layover required as a percentage of link travel time
- \( tt_l \): travel time on link \( l \), including running \( (tr_l) \) and dwell \( (td_l) \) times (min)
- \( h \): headway (min)

iv. Link-level Revenue (\( r_l \)):

\[ \eta = \gamma_f \times d_l, \]

where:

- \( \eta \): revenue of the transit link per hour ($/h)
- \( \gamma_f \): transit fare per boarding ($/boarding)
- \( d_l \): hourly ridership on link \( l \) (boarding/h)

In light of the above, the following travel impedance is calculated and assigned to each link:

\[ \mu_l = c_l - r_l = \gamma_o \left[ \frac{\delta \times tt_l}{h} \right] - \gamma_f \times d_l = \gamma_o \delta \left[ \frac{tr_l + td_l}{h} \right] - \gamma_f \times d_l \]
Using the link impedance function above, a candidate transit route alignment can be generated by minimizing the total impedance between the route origin and destination using a typical shortest path algorithm. Accordingly, the optimal transit route alignment that minimizes operating cost while maximizes route-level ridership is represented by the following relationship:

\[
\text{Min } \mu = C - R = \sum_{i=1}^{L} (c_i - \eta_i) = \sum_{i=1}^{L} (\gamma_o \left[ \frac{\delta \times tt_i}{h} \right] - \gamma_f \times d_i) = \sum_{i=1}^{L} (\gamma_o \delta \left[ \frac{tr_i + td_i}{h} \right] - \gamma_f \times d_i)
\]

**MODEL FORMULATION**

Given a feasible road network represented by a set of nodes (N), set of feasible links (L), two terminal nodes (o and d), and link impedance, DSCRGA starts with a buffer analysis with a specified threshold in order to estimate the potential transit demand around each link. Such threshold is identified based on the characteristics of the offered transit technology and the surrounding land use. This paper deals with bus-based transit service such that, up to 400 m between either passenger’s origin or destination and the transit service is considered an acceptable access/egress distance (19). The expected hourly transit demand suitably covered by link (l) is then calculated at the link-level. This is followed by assigning the impedance function \((\mu_l = c_l - \eta_l)\) to each link. The optimal transit route alignment is then calculated by minimizing the impedance between the route origin and destination using a typical shortest path algorithm.

Determining the optimal route alignment that maximizes route-level ridership can be specified in terms of the following linear programming problem. Given the graph (N, L) with origin node (o) and destination node (d), in addition to the travel impedance per link \((\mu_{ij}>=0)\) associated with each link \((i, j)\) in L, consider the following program that minimizes \(z\) with decision variables \(x_{ij}\) for all arcs \((i, j)\) in L.

\[
\text{Minimize } z = \sum_{i} \sum_{j} \mu_{ij} x_{ij},
\]

**Subject to:**

\[
\sum_{j} x_{ij} - \sum_{k} x_{ki} = \begin{cases} 
1 & \text{if } i = o \text{ (origin)}, \\
-1 & \text{if } i = d \text{ (destination)}, \\
0 & \text{otherwise}
\end{cases}
\]

\(x_{ij} \in \{0,1\} \) for all arcs \((i, j)\) in the network

The previous model represents a shortest path problem formulation which can be solved using a typical shortest path algorithm. Although DSCRGA might generate a longer route with longer in-vehicle travel time than that estimated by CRGA, previous research showed that among transit trip travel time components, both in-vehicle travel time and waiting time have a tradeoff relationship such that the expected increment in in-vehicle travel time would be balanced with the decrement in the waiting time (16, 22). Obviously, a transit route that provides a direct connection gives shorter in-vehicle travel time, but passengers will suffer from longer waiting time due to the reduced amount of demand per route. On the other hand, a circuitous transit route provides longer in-vehicle travel time, however, waiting time is expected to be shorter due to the
higher frequency of routes resulted from the concentrated demand per route. A further
distinguishable difference between transit and auto demand assignment is that the higher the
transit demand for trips on a route, the better the quality of service provided. In this essence, a
longer transit route with a higher frequency might be more desirable. Knowing that route
frequency is primarily determined by transit demand on any route, a longer transit route can be
accepted if it will be associated with an increment in demand and hence an improvement in the
level-of-service provided by the transit agency in terms of lower headways and higher
frequencies, which is the objective of the DSCRG A. However, the operational feasibility of the
generated route with respect to minimum and maximum route length constraints (C_{min} \leq \text{route length} \leq C_{max}) should be checked with upper and lower bounds on route lengths to ensure that its
length is not too long or too short. In addition, route directness in terms of route’s deviation from
shortest path (i.e. detour index= 1.2 - 1.5 times the shortest route) can also be considered as
maximum bound. If the route satisfies those constraints, then it is accepted as a candidate transit
route. Otherwise, it is removed from the solution space and another alternative route is
generated. This can be achieved by successively removing every link of the previously generated
route by inducing a large penalty for using it and solving the program between the same origin
and destination again, and finally releasing the clamped link.

ILLUSTRATIVE EXAMPLE

This section provides an illustrative example of the proposed algorithm for demand-sensitive
candidate route generation. Importantly, note that the following road network topology,
distribution and pattern of transit demand are chosen arbitrarily; hence, the outcomes of this
section should be considered merely an illustration of the approach, not a case study. In a real-
world application, data required for this analysis would be acquired from different sources (e.g.
transit agency for ridership data, public/private source for transport network and congestion data,
etc.).

Figure 4 shows a simple road network composed of 12 nodes, and 17 links. Link travel times in
minutes are shown on each link. In addition, the expected hourly transit demand within 400 m
from each link is identified using a buffer analysis.
Table 1 shows details on various trip travel time components and expected hourly demand at the link-level. The dwell time on each link (tdₙ) is assumed to be 2.5 sec/boarding (23). It is assumed that the dwell time on each link will be evenly split between the two end stops. For simplicity, total layover at both terminals (ty) is assumed to be 10% of the cycle time (i.e. δ= 1.1) and headway (h)= 10 min. It is also assumed that trip travel time and demand distribution are the same in both directions. Operating cost per vehicle hour of operation (γₒ) is estimated as 100.55 $/veh-h and transit fare (γᵢ) is estimated as 2.25 $/boarding. These estimates represent typical values in Kelowna, BC (24).
Using the traditional route generation algorithm (CRGA), a transit route is generated based on minimizing the link travel times between the route’s origin and destination without considering the distribution and pattern of demand along the route. The generated route has a length of 6.80 km, running time of 13.91 minutes, travel time of 17.24 minutes, and serving a demand of 80 boarding/h. However, the generated route failed to maximize the route-level ridership, as shown in Figure 5.
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As an alternative solution to maximize the expected ridership at the route-level while minimizing the cost of operation, a candidate route is generated using the DSCRGA. First, a 400 m buffer is created around each road link in order to identify the potential hourly transit demand. Then, the travel impedance per link is calculated as the difference between link’s operating cost and revenue ($\mu_l = c_l - r_l$).

The generated route using the DSCGRA has a length of 6.80 km, running time of 15.78 minutes, travel time of 23.28 minutes, and serving a demand of 180 boarding/h with a minimum total
impedance of 109.98 $/h instead of 201.44 $/h for that calculated using the traditional route generation algorithm. A comparative analysis for CRGA and DSCRGA is shown in Table 2.

<table>
<thead>
<tr>
<th></th>
<th>CRGA</th>
<th>DSCRGA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generated Route</td>
<td>10-14-7-8-9</td>
<td>1-2-12-6-17</td>
</tr>
<tr>
<td>Total Impedance ($/h)</td>
<td>201.44</td>
<td>109.98</td>
</tr>
<tr>
<td>Route Length (km)</td>
<td>6.8</td>
<td>6.8</td>
</tr>
<tr>
<td>Running Time (min)</td>
<td>13.91</td>
<td>15.78</td>
</tr>
<tr>
<td>Travel Time (min)</td>
<td>17.24</td>
<td>23.28</td>
</tr>
<tr>
<td>Demand Served (boarding/h)</td>
<td>80</td>
<td>180</td>
</tr>
<tr>
<td>Fleet Size (bus)</td>
<td>4</td>
<td>6</td>
</tr>
</tbody>
</table>

In terms of both running and travel times, the generated route using DSCRGA is 13.44% and 35.03% longer than that generated using the traditional approach, respectively. However, the generated route is 125% higher in terms of route-level ridership. Further, the number of transit units required to operate the generated routes can be calculates by dividing the cycle time by the headway (T/h) resulting in 37.94/10= 4 and 51.22/10= 6 buses for CRGA and DSCRGA, respectively. While more buses are required to operate the demand-sensitive route, the average cost for picking up a single passenger for the whole route shows that the demand-sensitive route is better with an average cost of 0.611 $/boarding (109.98/180), compared to 2.518 $/boarding (201.44/80) for the traditional route. The comparative analysis above shows that the transit route generated using DSCRGA is better than that generated using CRGA from both demand and operators satisfaction viewpoints (i.e. maximizing transit ridership while minimizing the cost of operation). Nevertheless, a major limitation of DSCRGA is the required detailed route-level demand data.

CONCLUSIONS
An attractive and efficient public transit service is an indispensable component of major metropolitan areas as well as Small and Rural Communities (SRCs). Hence, cities of all sizes are investing in accessible, affordable, fast, and frequent transit initiatives to increase the attractiveness and use of the service. Throughout the decades, numerous mathematical, heuristic and evolutionary solution methods were developed to deal with various aspects of the route design problem such as route configuration and/or other related design parameters in either a sequential or a joint manner. However, most transit route design approaches assume a fixed set of transit routes and demand, although transit demand is sensitive to route alignment, land use, and service quality. While some attempts considered the variability of transit demand, they still suffered from the spatial aggregation of demand, meaning that they failed to realize that trips are point-to-point not zone-to-zone.

This paper presented a demand-sensitive candidate route generation algorithm (DSCRGA) that is built on top of a Geographic Information Systems platform to be easily accessible and flexible to the designer and to better facilitate and visualize results. The DSCRGA accounts for the distribution of transit demand along the generated route and aims to maximize transit ridership at the route-level. The proposed algorithm has a simple generic objective function that captures both users’ and operator’s needs through minimizing the difference between route’s operating...
cost and revenue. Tackling such objectives makes the DSCRGA not only useful to generate route(s) for fixed-route mass transit services, but also for paratransit where service targets specific type of demand (e.g. flex-route and demand responsive services).

By ensuring suitable access to potential transit demand, the proposed approach implicitly accounts for the access time component of the total transit trip travel time which is commonly neglected in the current practice that accounts only for the in-vehicle travel time.

From a transit service design view point, maximizing the route-level ridership is a desirable objective, which is the main objective of the DSCRGA. However, in order to provide a complete route design toolkit for the planner, and knowing that transit stops are the first points of contact between the passenger and the transit service, a demand-sensitive candidate stop allocation algorithm (DSCSAA) is suggested for further work to maximize the transit ridership at the stop level.
References
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