A Review of Bus Route Network Design Procedures: Multi-objective optimization using Evolutionary Algorithms

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**Bus route network design (BRND)**

**Configuration and performance of Bus route network**

- **Approach**
  
  Efficient utilization of resources depending upon optimal networking of routes and frequency of buses.

- **Transitions in optimization procedures over time**
  
  - Mathematical and heuristic
  - Meta-heuristic approaches
  
  - Single objective optimality
  - Multi-objective optimality

- **Multi-Objective Approach**

  How efficient all components of bus transit system are being integrated?

- **Efficiency**

  Depending on stages involved in procedure
Bus route network design stages and components

1. Objective function
   - Single Objective
   - Multi Objective
     - Passenger
     - Operator

2. Data required
   - Demand estimation
   - Decision variables

3. Assignment models
   - Hybrid transit trip assignment
   - Multiple transit trip assignment
   - All-or-Nothing demand assignments
   - Hyper path transit assignment
   - Capacity-constrained traffic assignment
   - Stochastic User Equilibrium assignment

4. Optimization algorithms
   - Route Construction
   - Shortest path algorithms
     - Dijkstra shortest path algorithm
     - K-shortest path algorithm
     - Yen’s kth shortest path algorithm
   - Heuristics
   - Meta-Heuristics
     - Evolutionary algorithms
       - Type 1: Genetic Algorithm
       - Type 2: Simulated annealing
       - Type 3: Immune Clone Annealing
BRNDP - Multi-Objective functions

1. Objective function
   - Single Objective
   - Multi Objective
     - Passenger
     - Operator
   - Constraints

Weighted sum
- Bi level mixed integer
- Pareto optimality

Type 1: Weighted sum approach

Minimize: \( Z = A \sum_{i=1}^{i=n-1} \sum_{j=i+1}^{j=n} d_{ij} p_{ij} + B \sum_{i=1}^{i=n-1} \sum_{j=i+1}^{j=n} d_{ij} t_{ij} \)

Objectives being aggregated in a weighted function and converted into single objective function.
BRNDP - Multi-Objective functions

1. Objective function

   Single Objective
   Multi Objective

   Passenger
   Operator

   Constraints

   Weighted sum
   Bi level mixed integer
   Pareto optimality

Type 2: Bi level Mixed integer

- Upper level of the model
  Weighted sum or Pareto
- Lower level of the model
  Passenger trip assignment models

Model of the leader and follower game
BRNDP - Multi-Objective functions

1. Objective function
   - Single Objective
   - Multi Objective
     - Passenger
     - Operator
   - Constraints

- Weighted sum
- Bi level mixed integer
- Pareto optimality

Type 3: Pareto optimality

鉴别

乘客视角

\[ \text{Minimize: } C_p = A \sum_{i=1}^{i=n-1} \sum_{j=i+1}^{j=n} d_{ij} p_{ij} + B \sum_{i=1}^{i=n-1} \sum_{j=i+1}^{j=n} d_{ij} t_{ij} \]

鉴别

运营者视角

\[ \text{Minimize: } C_o = \sum_{l=1}^{r} L_l \]

没有单一的全局解决方案

乘客和运营者成本相互抵消作为双重目标

URBAN MOBILITY CONFERENCE INDIA - RESEARCH SYMPOSIUM, 05 December 2013
BRNDP – Three Multi-Objective Perspectives followed:

1. **User + Operator perspective**
   - Based on:
   - Minimizing \( (\text{Total User’s travel cost}) + (\text{Total Operating Cost}) \)

2. **Including Externalities**
   - Based on:
   - Minimizing \( (\text{Users’ costs}) + (\text{Operator’s costs}) + (\text{External Cost}) \)

3. **Including Transfer, Unsatisfied demand, Round trips**
   - Based on:
   - Minimizing
   - Passenger cost [satisfied demand [in-vehicle travel time + waiting time + transfer penalty]
     + unsatisfied demand]
   - + Operator Cost [Round trip time + waiting time at round trip + frequency of kth route]
## BRNDP - Variation of Constraints

<table>
<thead>
<tr>
<th></th>
<th>Frequency feasibility</th>
<th>Load Factor</th>
<th>Trip length</th>
<th></th>
<th>Length of bus lanes</th>
</tr>
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<tbody>
<tr>
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<td></td>
<td></td>
<td></td>
<td>3</td>
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<td>6</td>
<td>Transfer related</td>
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<td></td>
</tr>
<tr>
<td>7</td>
<td>Budget constraints of operating agencies</td>
<td></td>
<td></td>
<td>9</td>
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<td>8</td>
<td>Demand allocation constraints</td>
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<td>10</td>
<td>Round trip</td>
</tr>
<tr>
<td>9</td>
<td>Unsatisfied transit demand</td>
<td></td>
<td></td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Accessibility</td>
<td></td>
<td></td>
<td>12</td>
<td>Geographical &amp; land use</td>
</tr>
<tr>
<td>11</td>
<td>Route directness</td>
<td></td>
<td></td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Maximum number of nodes and routes</td>
<td></td>
<td></td>
<td>14</td>
<td></td>
</tr>
</tbody>
</table>
Objective function

- Multi objective function
- Weighted sum approach
- Bi level mixed integer
- Pareto optimality

Constraints
- Frequency
- Load factor
- Fleet size
- Trip length
- Bus lanes
- Transfer

Passenger Demand Assignment

Optimization Procedure

Sensitivity Analysis

Minimize: \[ Z = A \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} d_{ij} p_{ij} + B \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} d_{ij} t_{ij} \]

Minimize: \[ C_o = \sum_{l=1}^{r} L_l \]

Constraints:
- \( f_{\text{min}} \leq f_k \leq f_{\text{max}} \)  frequency constraint
- \( S_k \leq C \)  Capacity Cosntraint
- \( F_{\text{max}} \)  Fleet size constraint
- \( x_{i,j} \leq x_{\text{max}} \)  Maximum transfer constraint
Components of Bus Route Network Design

1. Objective function
   - Single Objective
   - Multi Objective
     - Passenger
     - Operator
   - Constraints
     - Type 1: Pareto optimality models
     - Type 2: Bi level mixed integer models
     - Type 3: Weighted sum models

2. Data required
   - Demand estimation
   - Decision variables
   - Design variables
   - Demand parameters
   - Operational parameters
   - Transfer related parameters
   - Travel time parameters
   - Network structure parameters

3. Assignment models
   - Hybrid transit trip assignment
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Demand estimation as Multi-dimensional approach

Depending on factors determined by user and operators

Level of service + Perception of operational agency + Configuration of Bus transit network structure + …
BRNDP – Demand Estimation issues

1. Fixed Demand
   Assuming demand given in network

2. Variable demand versus Fixed demand
   Variable relationship between Transit demand and network configuration

   Toward optimum solution

   Re-estimation of demand based on:
   Peak time and non-peak time

   + Demand forecasting models
     4 step model or
     Describe choice models
BRNDP – Parameters – Design and Decision Variables

- Demand Parameters
- Operational Parameters
- Transfer related Parameters
- Travel time Parameters
- Network structure Parameters

- Length of the routes
- Number of lanes
- Maximum Number of routes
BRNDP – Procedure and components

Objectives function
Multi objective function
Weighted sum approach
Bi level mixed integer
Pareto optimality

Optimization Procedure
1. Initial route set construction
2. Small and Big network testing
3. Sensitivity Analysis
4. Constraints
   - Frequency
   - Load factor
   - Fleet size
   - Trip length
   - Bus lanes
   - Transfer
5. Data required
   - Parameters
     - Demand
     - Operational
     - Transfer related
     - Travel time related
     - Network structure
   - Design variables
   - Decision variables
6. Demand Estimation Modeling
7. Initial route set construction
8. Small and Big network testing
Bus route network design components

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BRNDP – **Passenger demand Assignment**

**Assignment Models**

- Hybrid transit trip assignment
- Multiple transit trip assignment
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- Stochastic User Equilibrium assignment
**Objective function**
- Multi objective function
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**Data required**

**Constraints**
- Frequency
- Load factor
- Fleet size
- Trip length
- Bus lanes
- Transfer

**Passenger Demand Assignment**

**Initial route set construction**
- Route Construction Module
- Shortest path algorithm
- Feasibility Assessment
- Connectivity Assessment

**Optimization Procedure**

**Small and Big network testing**

**Sensitivity Analysis**
Bus route network design components

1. Objective function
   - Single Objective
     - Passenger
     - Operator
   - Multi Objective
     - Demand estimation
     - Decision variables
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BRNDP – Optimization

Step 1: Route construction

Step 2: Shortest path algorithms
- Dijkstra shortest path algorithm
- K-shortest path algorithm / Yen’s

- Heuristics
- Meta-Heuristics

Step 3: Evolutionary algorithms
- Type 1: Genetic Algorithm
- Type 2: Simulated annealing
- Type 3: Immune Clone Annealing
BRNDP – Route construction procedure

1. Candidate route set generation
   Identify initial route set using shortest path algorithms
   - Dijkstra shortest path algorithm
   - K-shortest path algorithm / Yen’s

2. Applying heuristics to check
   - Feasibility checking
   - Connectivity checking
   - Route evaluation modules
   - Frequency setting > Simultaneously or Separately

3. Applying optimization procedure
   - Find optimum set of solutions
   - Heuristic
   - Meta-Heuristic
BRNDP – Example

Connectivity check
Example:
Depth-first search
breadth-first search

Initial Route set:

<table>
<thead>
<tr>
<th>Number of routes</th>
<th>Route description</th>
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<tbody>
<tr>
<td>4</td>
<td>9-13-12-10-11-3-1-0</td>
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<tr>
<td></td>
<td>11-10-9-7-5-2-1-0</td>
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<tr>
<td></td>
<td>4-3-11-10-9-6-14-8</td>
</tr>
<tr>
<td></td>
<td>10-9-7-5-3-4-1</td>
</tr>
</tbody>
</table>

Initial route set construction
Route Construction Module
Shortest path algorithm
Feasibility Assessment
Connectivity Assessment

Small and Big network testing

Data required
BRNDP – Example

Objective function

Passenger Demand Assignment

Optimization Procedure
Meta-Heuristic approach
Evolutionary algorithm
Genetic algorithm
Simulated annealing
Immune clone annealing

Sensitivity Analysis

Genetic algorithm operation

Optimum solution

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<tr>
<th>String</th>
<th>Substring-2</th>
<th>Substring-1</th>
<th>$x_2$</th>
<th>$x_1$</th>
<th>$f(x)$</th>
<th>$F(x)$</th>
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<tbody>
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<td>126.685</td>
<td>0.008</td>
</tr>
</tbody>
</table>
BRNDP – Example

Small Network test

Real size Network test

Data required

Initial route set construction

Small and Big network testing
Key issues to optimum solution in BRND

1. Demand Estimation methods
2. Route construction heuristics
   - Route Evaluation parameters
3. Effect of more complex parameters in optimum solution set
   - Bus stop spacing, accessibility to bus stops
4. Effect of different operators in Evolutionary algorithms
BRNDP – Procedure and components

Objective function
- Multi objective function
- Weighted sum approach
- Bi level mixed integer
- Pareto optimality

Data required
- Design variables
- Decision variables

Parameters
- Demand
- Operational
- Transfer related
- Travel time related
- Network structure

Passenger Demand Assignment

Optimization Procedure
- Meta-Heuristic approach
- Evolutionary algorithm
- Genetic algorithm
- Simulated annealing
- Immune clone annealing

Constraints
- Frequency
- Load factor
- Fleet size
- Trip length
- Bus lanes
- Transfer

Initial route set construction
- Route Construction Module
- Shortest path algorithm
- Feasibility Assessment
- Connectivity Assessment

Small and Big network testing
- Different types of network

Sensitivity Analysis
- Sensitivity to evolutionary algorithm operators
- Sensitivity to parameters

Constraints
- Frequency
- Load factor
- Fleet size
- Trip length
- Bus lanes
- Transfer

1

2

3

4

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7
Title
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Thank You

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