Outline

- Transfers and network connectivity
- Network structure
- Approaches to Network Design


Service connectivity is affected by

- System elements
- Transfer facility elements
- Service elements

A Framework For Improving Connectivity

Transfers are a basic characteristic of public transport
- necessary for area coverage
- typically 30-60% of urban public transport trips involve multiple public transport vehicles
- a major source of customer dissatisfaction contributing
  - uncertainty
  - discomfort
  - waiting time
  - cost
- often ignored in service evaluation and planning practice

System Elements

<table>
<thead>
<tr>
<th>Transfer Price</th>
<th>Pre-Trip Information</th>
<th>Fare Media</th>
<th>In-vehicle Information</th>
<th>Fare Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Free</td>
<td>System information</td>
<td>Same</td>
<td>Real-time and connecting</td>
<td>No validation needed, and can leave public</td>
</tr>
<tr>
<td></td>
<td>with trip planner</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Discounted</td>
<td>System information</td>
<td>Connecting route information, transfer announcements</td>
<td>No validation needed if remaining in public transportation space</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full additional</td>
<td>Route information</td>
<td>Connecting route information</td>
<td>Validation needed, but no delay added to trip</td>
<td></td>
</tr>
<tr>
<td>fare</td>
<td>No information</td>
<td>Different</td>
<td>No information</td>
<td>Validation adds delay to trip</td>
</tr>
</tbody>
</table>

© MIT. All rights reserved. This content is excluded from our Creative Commons license. For more information, see https://ocw.mit.edu/help/faq-fair-use/
### Transfer Facility Elements

<table>
<thead>
<tr>
<th>Weather protection</th>
<th>En-Route information</th>
<th>Changing Levels</th>
<th>Road Crossings</th>
<th>Walking Distance</th>
<th>Concessions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fully-protected</td>
<td>Real-time, system,</td>
<td>No vertical separation</td>
<td>No road crossing required</td>
<td>No walking required</td>
<td>Large selection</td>
</tr>
<tr>
<td>connection</td>
<td>facility, and schedule information</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Covered connection</td>
<td>System, facility,</td>
<td>Vertical separation with assistance</td>
<td>Road crossing required, but assisted</td>
<td>Short walk required</td>
<td>Small selection</td>
</tr>
<tr>
<td>Covered waiting area</td>
<td>and schedule</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open waiting area</td>
<td>No information</td>
<td>Vertical separation without assistance</td>
<td>Unassisted road crossing</td>
<td>Long walk required</td>
<td>None</td>
</tr>
</tbody>
</table>

### Service Elements

<table>
<thead>
<tr>
<th>Transfer Waiting Time</th>
<th>Span of Service</th>
</tr>
</thead>
<tbody>
<tr>
<td>High frequency</td>
<td>Matched</td>
</tr>
<tr>
<td>Matched headways and coordinated arrivals and departures</td>
<td></td>
</tr>
<tr>
<td>Coordinated arrivals and departure</td>
<td></td>
</tr>
<tr>
<td>No coordination</td>
<td>Unmatched</td>
</tr>
</tbody>
</table>

### Radial (with limited circumferential)

- **To obtain large share of trips to city center**
- **Observations**
  - transit has strongest competitive position with respect to auto for CBD
    - high parking prices
    - limited parking availability
    - auto congestion on radial arterials
  - CBD market has been declining share of all urban trips
  - network effectiveness for non-CBD trips is poor
- **Conclusions**
  - effectiveness depends on specifics of urban area
    - strength of CBD as generator
    - highway/auto/parking characteristics
    - overall level of transit ridership

### Grid and Timed Transfer

- **Aims**
  - provide reasonable level of transit service for many O-D pairs
  - decrease the perception of transfers as major disincentive for riders
- **Observations**
  - must avoid negative impact on CBD ridership
  - what is impact of restricting headways to set figure, e.g. 30 minutes?
  - how much extra running time is required to guarantee connections?
  - will transit be competitive in non-CBD markets?
  - well-located transfer centers can enhance suburban mobility
- **Conclusions**
  - grid systems work well with high ridership and dispersed travel patterns
    - New York City, Toronto, Los Angeles
    - high frequencies reduce need for timed transfers
  - timed transfers work well for urban areas with dispersed focused suburban activity centers, multi-modal networks
Multimodal

- To provide effective service for both short and long trips
- Observations
  - rail (or other guideway) networks are expensive to build and hence network is limited in length
  - rail capacity is high, marginal cost of carrying passengers relatively low
  - for new rail lines
    - is direct bus service retained?
    - are passengers forced to transfer to rail?
- Conclusions
  - need to look at total trip time and cost to determine net impact on different O-D trips
  - build integrated bus/rail fare policy to encourage riders to take fastest route

Approaches to Network Design

- Incremental Improvements
  - seek opportunities to intervene locally in network
  - computer simulation – detailed analysis tool
- Global Network Design – synthesize new network
  - fully automated
  - man/machine interaction

© National Academies of Sciences. All rights reserved. This content is excluded from our Creative Commons license. For more information, see https://ocw.mit.edu/help/faq-fair-use/.
Computer Simulation

- Tool to answer what-if questions
- Functions
  - specify system (e.g., route characteristics) and operating environment
  - model estimates performance – transit ridership, costs, etc.
  - revise as desire and re-run
- Not heavily used for route design, tends to be incremental
- Examples
  - EMME
    - multimodal
    - full equilibrium
  - MADITUC
    - public transportation
    - fixed transit demand matrix
  - strong interactive graphics capabilities for network displays travel flows

Differentiating Features of Bus Network Models

- Demand
  - assumed constant
  - assumed variable based on service design
- Objective Function
  - minimize generalized cost
  - maximize ridership
- Constraints
  - fleet size
  - operating budget
  - vehicle capacity
- Passenger Behavior
  - system or user optimizing
  - single or multiple path assignment
- Solution Technique
  - partition into route generation and frequency determination

Incremental Improvement

Aims
- examine load profiles of individual routes looking for improvement opportunities
- obtain routes characterized by high frequencies and fairly constant loads

Strategies
- route decomposition
  - where frequency is high but load is variable along route
- route aggregation
  - combine parallel routes to improve frequency or through-route to reduce transfers
- new services
  - reduce circuitry and operating cost, access new markets

Route Disaggregation Options
New Direct Services

VIPS-II Package

- Basic premises
  - fully automated planning systems won't work
  - computer role is to number crunch and organize information
  - also solve specific sub-problems
  - need interactive graphics for good man-machine communication
  - need variable demand
- Objective
  - Maximize number of passengers subject to constraints
    - operator cost
    - minimum level of service
- 1987 upgrade
  - passengers can be aware/unaware of timetable
  - headways between routes can be coordinated
  - stops and modes can have different disutility weights
  - congestion causes delays and uneven headways

VIPS-II Package

- Applications
  - route network analysis
  - frequency optimization
- Inputs
  - network
  - fare structure
- Outputs
  - costs
  - revenues
  - productivity
  - travel times
  - level of service
  - route choice

General Model Structure

Specific Sub-Problems

- evaluation of a proposed network
- frequency determination for given routes
- linking routes at junction
- generation of initial route network
Network Design Approaches

- Start with fully connected network
  - eliminate the weakest routes iteratively
  - reassign passenger flows to the best remaining routes
- Generate a large number of possible routes heuristically
  - based on the following route design principles:
    - most high demand O-D pairs should be served directly
    - only certain modes are suitable for route terminal
    - routes should be direct and not be circuitous
    - routes should meet to facilitate transfers
  - Select final set of routes through optimization problem formulation

Source: https://www.flickr.com/photos/city-planner/16732124571/in/pool-2327386@N22
© city-planner. License: CC BY-SA. Some rights reserved. This content is excluded from our Creative Commons license. For information, see https://ocw.mit.edu/help/faq-fair-use/

Source: http://remix.com/

QGIS

Source: http://remix.com/