how do european cities manage public transport and land use integration?

Dr Jan Scheurer, RMIT/Curtin University, Melbourne/Perth
spatial network analysis for multimodal urban transport systems (SNAMUTS)

Purpose: To assess and quantify how transport networks, in terms of geographical configuration and service levels, perform in their urban context (distribution of land use activities).

SNAMUTS was inspired by the Space Syntax approach (Hillier and Hanson, 1984), and the Multiple Centrality Analysis tool (Porta, Crucitti and Latora, 2006)

SNAMUTS is a supply-side tool: it does not provide predictions about usage or capacity levels. Rather it asks: What is the role of the public transport system in facilitating movement and activity across a city region?
Create a ‘network effect’ by local optimisation to routes, good interchange facilities, high and standardised service frequencies, timetable coordination and the presence of orbital/cross-suburban routes to maximise market penetration for public transport.

Spatial separation or impediment measure: Travel time divided by service frequency \( (d = \frac{4t}{\sqrt{f}}) \)

Minimum service standard (SNAMUTS 23): 20 min frequency during the weekday interpeak, 30 min on Sat/Sun (buses, trams), 30 min weekdays and 7 day service (rail, ferry)

Identifying activity nodes: SNAMUTS matrix of activity nodes derived from activity centre hierarchy in strategic planning documents and from field observation. Average activity node catchments should be between 10,000 and 20,000 residents and jobs.
6 key snamuts indicators

- Closeness Centrality
  ‘Ease of Movement’
- Degree Centrality
  ‘Transfer Intensity’
- 30-minute Contour Catchment
- Betweenness Centrality
  ‘Geographical Distribution of Travel Opportunities’
- Network Stress
  ‘Identifying Squeeze Points and Underused Potential’
- Nodal Connectivity
  ‘Attractiveness for PT-oriented Land Use Intensification’

Composite Index: combines all 6 measures by allocating between 0 and 10 points to each (maximum 60)
overview of Snamuts indicators

1. **Service intensity**: How much operational input is required to run the network at the defined minimum service standard?

2. **Closeness centrality**: What is the ease of movement between a node and the rest of the network?

3. **Degree centrality**: How many transfers separate a node from the rest of the network?

4. **Catchment size of 30-minute travel time contour**: How many residents and jobs are accessible within half an hour?

5. **Betweenness centrality**: How are travel opportunities geographically distributed across the network?

6. **Network Stress**: Where on the network can we find mismatches between route or node significance and level of service?

7. **Nodal connectivity**: How are activity centres placed to act as hubs for the network?
Copenhagen: Service Intensity

Number of vehicles/train sets required in simultaneous operation for the minimum standard network (SNAMUTS 23R)

- S-Tog og Regionaltog: 102
- Metro: 16
- Bus: 341
- Færge: 3

Total: 459
24.8 per 100,000 pop (2012)
## Comparison of Service Intensity

<table>
<thead>
<tr>
<th>City</th>
<th>Service Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Edinburgh</td>
<td>38.2</td>
</tr>
<tr>
<td>Amsterdam</td>
<td>28.7</td>
</tr>
<tr>
<td>Zürich</td>
<td>25.9</td>
</tr>
<tr>
<td>Wien</td>
<td>25.5</td>
</tr>
<tr>
<td>Oporto</td>
<td>24.9</td>
</tr>
<tr>
<td>København</td>
<td>24.8</td>
</tr>
<tr>
<td>Barcelona</td>
<td>22.5</td>
</tr>
<tr>
<td>Zuid Holland</td>
<td>16.8</td>
</tr>
<tr>
<td>Hamburg</td>
<td>16.5</td>
</tr>
<tr>
<td>Utrecht</td>
<td>16.2</td>
</tr>
<tr>
<td>München</td>
<td>14.2</td>
</tr>
</tbody>
</table>
Operational efficiency: Networks dominated by slow modes (especially buses) tend to require greater operational input (in number of vehicles/drivers) than networks dominated by fast modes (especially light or heavy rail).

Performance expectation: Does a higher outlay of operational resources consistently result in better public transport accessibility and network performance?
why does Edinburgh have by far the highest service intensity figure?
why does edinburgh have by far the highest service intensity figure?

high dependence on buses; deregulation regime leads to competition between operators
why does munich have the lowest service intensity figure?
why does munich have the lowest service intensity figure?

frugal network planning:
avoidance of parallel rapid rail and surface routes,
high reliance on rail, relatively low frequencies
Comparison of service intensity: the Nordic imbalance

<table>
<thead>
<tr>
<th>City</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Edinburgh</td>
<td>38.2</td>
</tr>
<tr>
<td>Amsterdam</td>
<td>28.7</td>
</tr>
<tr>
<td>Zürich</td>
<td>25.9</td>
</tr>
<tr>
<td>Wien</td>
<td>25.5</td>
</tr>
<tr>
<td>Oporto</td>
<td>24.9</td>
</tr>
<tr>
<td>København</td>
<td>24.8</td>
</tr>
<tr>
<td>Barcelona</td>
<td>22.5</td>
</tr>
<tr>
<td>Zuid Holland</td>
<td>16.8</td>
</tr>
<tr>
<td>Hamburg</td>
<td>16.5</td>
</tr>
<tr>
<td>Utrecht</td>
<td>16.2</td>
</tr>
<tr>
<td>München</td>
<td>14.2</td>
</tr>
</tbody>
</table>
why is copenhagen’s service intensity higher than hamburg’s, despite similar roles for bus and rail?
Copenhagen has greater surface network density in the inner area than Hamburg.
Surface network layout in Copenhagen and Hamburg
Comparison of service intensity: the mystery of the Dutch Randstad

<table>
<thead>
<tr>
<th>Location</th>
<th>Service Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Edinburgh</td>
<td>38.2</td>
</tr>
<tr>
<td>Amsterdam</td>
<td>28.7</td>
</tr>
<tr>
<td>Zürich</td>
<td>25.9</td>
</tr>
<tr>
<td>Wien</td>
<td>25.5</td>
</tr>
<tr>
<td>Oporto</td>
<td>24.9</td>
</tr>
<tr>
<td>København</td>
<td>24.8</td>
</tr>
<tr>
<td>Barcelona</td>
<td>22.5</td>
</tr>
<tr>
<td>Zuid Holland</td>
<td>16.8</td>
</tr>
<tr>
<td>Hamburg</td>
<td>16.5</td>
</tr>
<tr>
<td>Utrecht</td>
<td>16.2</td>
</tr>
<tr>
<td>München</td>
<td>14.2</td>
</tr>
</tbody>
</table>
why is there nearly twice as much public transport service in amsterdam than in zuid holland? slower trams and buses?
why is there nearly twice as much public transport service in amsterdam than in zuid holland?
slower trams and buses?

average tram speed
amsterdam: 15.7 km/h
den haag/r’dam: 16.9 km/h
why is there nearly twice as much public transport service in amsterdam than in zuid holland?
better service frequencies?
why is there nearly twice as much public transport service in Amsterdam than in Zuid Holland?

better service frequencies?

average hourly trams per route segment, a'dam: 13.5
den haag/r'dam: 9.1
why is there nearly twice as much public transport service in Amsterdam than in Zuid Holland? A larger network?
why is there nearly twice as much public transport service in Amsterdam than in Zuid Holland?

a larger network?

network coverage (of metro activities), a’dam: 79.6%

Zuid Holland: 65.9%
Networks have topological properties (how many degrees of separation from A to B) and metric properties (how many units of distance/impediment from A to B)

Source: Porta, Crucitti and Latora 2006
What is the ease of movement across the network? [lower values indicate better accessibility performance]

Closeness Centrality
Average Minimum Cumulative Impediment to/from all other Nodes in the Network
Average: 48.4
<table>
<thead>
<tr>
<th>City</th>
<th>Closeness Centrality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wien</td>
<td>38.8</td>
</tr>
<tr>
<td>Barcelona</td>
<td>44.8</td>
</tr>
<tr>
<td>Oporto</td>
<td>46.4</td>
</tr>
<tr>
<td>Zürich</td>
<td>47.4</td>
</tr>
<tr>
<td>København</td>
<td>47.9</td>
</tr>
<tr>
<td>München</td>
<td>48.4</td>
</tr>
<tr>
<td>Amsterdam</td>
<td>48.8</td>
</tr>
<tr>
<td>Utrecht</td>
<td>49.2</td>
</tr>
<tr>
<td>Hamburg</td>
<td>51.9</td>
</tr>
<tr>
<td>Zuid Holland</td>
<td>62.9</td>
</tr>
<tr>
<td>Edinburgh</td>
<td>72.1</td>
</tr>
</tbody>
</table>
in larger networks, should we expect to typically find higher (poorer) average closeness results?
Closeness Centrality and network size

\[ y = 211.4e^{-0.007x} \]

\[ R^2 = 0.0334 \]
Closeness Centrality: what does and what doesn’t this index tell us?

Ease of movement: Closeness scores are a spatial separation measure for the activity centre network. They are inflated by:

1. dispersed settlement patterns,
2. detours forced by geographical barriers or missing links,
3. slow travel speeds,
4. low service frequencies,
or a combination of several of the above.

Why do three cities come out with ‘breakout performances’ from an otherwise quite even field on this index?
Vienna: compact and contiguous urban form/activity centre network, high service intensity, good penetration of urban area by rapid rail modes with 5-min frequencies

best average closeness score in the sample
Zuid Holland: second poorest average closeness score

Polynuclear form with many spatially separated settlement cores, low service intensity, limited rapid rail network with frequencies of 10 min or greater
Edinburgh: high reliance on buses with slow average speeds, limited rail network with typical 30-min frequencies, lack of integrated fares discourages transfers.

Poorest average closeness score in the sample.
What is the transfer intensity of the network?

[lower values indicate better accessibility performance]
Comparison of average degree centrality

<table>
<thead>
<tr>
<th>City</th>
<th>Centrality</th>
</tr>
</thead>
<tbody>
<tr>
<td>München</td>
<td>0.89</td>
</tr>
<tr>
<td>Edinburgh</td>
<td>0.89</td>
</tr>
<tr>
<td>Oporto</td>
<td>0.91</td>
</tr>
<tr>
<td>København</td>
<td>0.93</td>
</tr>
<tr>
<td>Amsterdam</td>
<td>1.08</td>
</tr>
<tr>
<td>Barcelona</td>
<td>1.11</td>
</tr>
<tr>
<td>Hamburg</td>
<td>1.12</td>
</tr>
<tr>
<td>Utrecht</td>
<td>1.17</td>
</tr>
<tr>
<td>Wien</td>
<td>1.20</td>
</tr>
<tr>
<td>Zürich</td>
<td>1.22</td>
</tr>
<tr>
<td>Zuid Holland</td>
<td>1.60</td>
</tr>
</tbody>
</table>
Network organisation: Is the public transport network organised around a modal hierarchy (higher transfer intensity)? Or do the networks of modes with different performance coexist (compete?) in spatial terms (lower transfer intensity)?

Network Density: are most activity nodes accessible by both radial routes and orbital routes (lower transfer intensity)? Or is there a significant number of nodes only accessible by short feeder routes to larger centres (higher transfer intensity)?

Regional settlement pattern: Relative self-containment of intra-urban public transport networks in polycentric agglomerations produces low transfer intensity at a local scale, but higher transfer intensity at a regional scale.
why does copenhagen outperform amsterdam on this index?
why does copenhagen outperform amsterdam on this index?

ams: neighbouring cities of almere and haarlem have their own bus systems, connected to amsterdam only by transfers to rail
why does copenhagen outperform vienna on this index?
why does copenhagen outperform vienna on this index?

vienna’s network has shorter routes. both networks are grid-shaped but copenhagen’s is more multi-directional
Contour Catchments

How many residents and jobs can you access within 30 minutes from each activity node?

Some assumptions:

One transfer is allowed within 30 min, but only between services that both run at least every 15 min.

A flat deduction applies for making the transfer, equivalent to the actual average transfer time across the network (usually between 6 and 8 minutes).
# Comparison of Network Coverage

<table>
<thead>
<tr>
<th>City</th>
<th>Coverage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wien</td>
<td>79.7%</td>
</tr>
<tr>
<td>Amsterdam</td>
<td>79.6%</td>
</tr>
<tr>
<td>Barcelona</td>
<td>77.5%</td>
</tr>
<tr>
<td>Zürich</td>
<td>74.5%</td>
</tr>
<tr>
<td>København</td>
<td>73.7%</td>
</tr>
<tr>
<td>Zuid Holland</td>
<td>65.9%</td>
</tr>
<tr>
<td>Oporto</td>
<td>63.5%</td>
</tr>
<tr>
<td>Utrecht</td>
<td>58.4%</td>
</tr>
<tr>
<td>Edinburgh</td>
<td>58.3%</td>
</tr>
<tr>
<td>Hamburg</td>
<td>57.3%</td>
</tr>
</tbody>
</table>
as seen earlier with the example of Amsterdam and Zuid Holland, network coverage should go up proportionally to service intensity – right?
network coverage and service intensity

\[ y = 12.258e^{0.9268x} \]

\[ R^2 = 0.0961 \]
Comparison of average 30-min contour catchments

<table>
<thead>
<tr>
<th>City</th>
<th>Catchment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wien</td>
<td>31.2%</td>
</tr>
<tr>
<td>København</td>
<td>29.7%</td>
</tr>
<tr>
<td>Barcelona</td>
<td>24.4%</td>
</tr>
<tr>
<td>Zürich</td>
<td>22.1%</td>
</tr>
<tr>
<td>Amsterdam</td>
<td>19.4%</td>
</tr>
<tr>
<td>Oporto</td>
<td>18.0%</td>
</tr>
<tr>
<td>Hamburg</td>
<td>16.7%</td>
</tr>
<tr>
<td>Utrecht</td>
<td>16.6%</td>
</tr>
<tr>
<td>Edinburgh</td>
<td>13.6%</td>
</tr>
<tr>
<td>Zuid Holland</td>
<td>10.8%</td>
</tr>
</tbody>
</table>
average contour catchments must surely be correlated to total population size – as in, the larger the city, the smaller the average relative contour catchment...
Contour catchments and population size

y = 1.732e^{0.9031x}
R^2 = 0.0146

Metropolitan Population (million)

Barcelona
Zuid Holland
Hamburg
Amsterdam
København
Edinburgh
Oporto
Zürich
Utrecht
Network coverage and contour catchments: what do and what don’t these indexes tell us?

Network coverage describes the quantity of people with access to public transport, while the contour catchment measure expands this with a qualitative message (how many people can you access within 30 minutes?)

Network coverage thus serves as a proxy for the commitment of decision makers across a metropolitan area to provide a certain level or public transport (in spatial terms).

The contour catchment assesses how successfully such commitment translates into the practical penetration of the settlement area with useful public transport journey paths.
How are travel opportunities distributed across the network?

Betweenness centrality defines preferred travel paths between each pair of nodes, and counts them at nodes and route segments to determine their strategic significance.
Comparison of global betweenness

1. Barcelona  2,485
2. Wien  1,574
3. Hamburg  1,320
4. Amsterdam  1,210
5. København  1,141
6. Zuid Holland  1,082
7. Zürich  891
8. Utrecht  655
9. Oporto  655
10. Edinburgh  574
sure! the larger this city, the higher the global betweenness score...
global betweenness and metro activities

$y = 1.2725e^{0.0007x}$

$R^2 = 0.747$
<table>
<thead>
<tr>
<th>Location</th>
<th>Average Nodal Betweenness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barcelona</td>
<td>76.0</td>
</tr>
<tr>
<td>Wien</td>
<td>46.6</td>
</tr>
<tr>
<td>København</td>
<td>43.7</td>
</tr>
<tr>
<td>Hamburg</td>
<td>41.4</td>
</tr>
<tr>
<td>Amsterdam</td>
<td>38.8</td>
</tr>
<tr>
<td>Utrecht</td>
<td>35.8</td>
</tr>
<tr>
<td>Oporto</td>
<td>31.0</td>
</tr>
<tr>
<td>Zuid Holland</td>
<td>30.7</td>
</tr>
<tr>
<td>Oporto</td>
<td>27.2</td>
</tr>
<tr>
<td>Zürich</td>
<td>26.7</td>
</tr>
</tbody>
</table>
this measure certainly has something to do with overall urban density?
average nodal betweenness and activity density

$y = 32.906 e^{0.0112x}$

$R^2 = 0.2845$
Public transport ‘movement energy’: Betweenness centrality attempts to quantify the presence of public transport opportunities in each centre, and across the metropolitan area, as well as visualise how this presence flows across the network.

Balanced and unbalanced nodes/places, stressed locations and routes: Betweenness can help identify pressures on network elements originating from either their land use or their transport function (or both in conjunction).

Betweenness scores are not necessarily proportional to usage levels, but correlations with usage can point to under- or over-utilised potential for public transport movement.
The betweenness centrality index rewards urban compactness/contiguity as well as high settlement density - two influences that can either amplify or neutralise each other in the real world.

The first factor explains Copenhagen’s and Hamburg’s good performance on this index, while a combination of both factors explains Barcelona’s, Vienna’s and Amsterdam’s.

Is this bias towards urban compactness a problem for this index?
segmental betweenness

Amsterdam 2010

Segmental Betweenness
Index for number of network paths that pass through route segment, weighted by combined activity catchment and cumulative impedance

Percentage of Rail/Metro/Tram/Bus segments:
32.7% / 13.5% / 16.6% / 37.2%

Percentage of CBD segments:
22.5%
Comparison of average network stress

- Zürich: 10.6
- Wien: 11.5
- Edinburgh: 12.2
- København: 15.1
- Amsterdam: 16.9
- Barcelona: 17.8
- Utrecht: 19.0
- Hamburg: 21.3
- Oporto: 22.5
- Zuid Holland: 23.7
i got it! the lower the service intensity, the higher the level of network stress – right?
network stress and service intensity

\[ y = 45.522e^{-0.04x} \]

\[ R^2 = 0.4537 \]
network stress: what does and what doesn’t this index tell us?

A ‘troubleshooting’ tool to pinpoint mismatches in public transport supply and (potential) demand (ie. demand as derived from urban form and network configuration)

Includes a feedback loop, as isolated measures to improve service levels to relieve stress (ie. frequency upgrades) will also add to network stress through greater ease of movement.

Responds most vigorously to more comprehensive solutions, such as network reconfigurations and mode upgrades.
To what extent do network nodes function as hubs for movement?

The connectivity index measures each node’s connectedness to other nodes, and its capacity for making transfers or stopovers.
Comparison of nodal connectivity

- Barcelona: 304
- Wien: 193
- München: 175
- Hamburg: 143
- Amsterdam: 123
- Zuid Holland: 86
- København: 86
- Zürich: 83
- Utrecht: 60
- Oporto: 47
so do average results on this index automatically go up with growing network size?
nodal connectivity and network size

\[ y = 97.417e^{0.0034x} \]

\[ R^2 = 0.5182 \]
alright then – what about network stress? wouldn’t that lead to higher occupancy figures, inflating the results on this index?
nodal connectivity and network stress

\[ y = 18.366e^{-0.04x} \]

\[ R^2 = 0.0302 \]
why do vienna and barcelona outperform copenhagen and zurich on this index?
why do vienna and barcelona outperform copenhagen and zurich on this index?

larger networks, bigger crowds!
6 key snamuts indicators

- Closeness Centrality
  ‘Ease of Movement’
- Degree Centrality
  ‘Transfer Intensity’
- 30-minute Contour Catchment
- Betweenness Centrality
  ‘Geographical Distribution of Travel Opportunities’
- Network Stress
  ‘Identifying Squeeze Points and Underused Potential’
- Nodal Connectivity
  ‘Attractiveness for PT-oriented Land Use Intensification’

Composite Index: combines all 6 measures by allocating between 0 and 10 points to each (maximum 60)
snamuts composite index

Amsterdam 2010
Composite Public Transport Accessibility Index

- Excellent (25-45.0 points)
- Very Good (22.5-25 points)
- Good (20-22.5 points)
- Above Average (17.5-20 points)
- Average (15-17.5 points)
- Below Average (12.5-15 points)
- Poor (10-12.5 points)
- Minimal (5.6-10 points)

Urbanised areas without minimum service

Average: 18.0
Comparison of Snamuts composite index

- Barcelona: 30.2
- Wien: 30.1
- København: 24.0
- Amsterdam: 21.5
- Zürich: 20.8
- Hamburg: 19.0
- Oporto: 17.2
- Utrecht: 16.7
- Zuid Holland: 15.9
- Melbourne: 15.5
- Sydney: 14.8
- Perth: 13.4
There seems to be a frugal approach and a generous approach to providing operational resources for public transport in European cities. The frugal approach generally maximises savings from network efficiencies with some (but not excessive) cost to ease of movement and connectivity. It also results in greater vulnerability to network stress.

The generous approach is based on maintaining a coexistence between rapid and surface modes on the same corridors for different transport tasks. By creating more travel options, it tends to improve connectivity and relieve network stress.
High service frequencies on the rapid rail trunk network are vital; the best-performing systems provide at least all-day 5-minute services on inner urban metro lines and 10-minute services across the suburban rail network.

The presence of orbital routes (rapid rail, tram or bus) can and does result in a better geographical spread of the flow of travel opportunities if these routes are operated at the same frequency as the radial ones, and are operated at sufficient speeds to provide travel time advantages for cross-suburban journeys over a transfer trip via the city centre.
mange tak – dank u wel – vielen dank – loads o’thanks – moltes gràcies – moito obrigado!

jan.scheurer@rmit.edu.au