Conference on Advanced Systems in Public Transport
19-23 July 2015, Rotterdam, The Netherland

Transit network design for small-medium size cities

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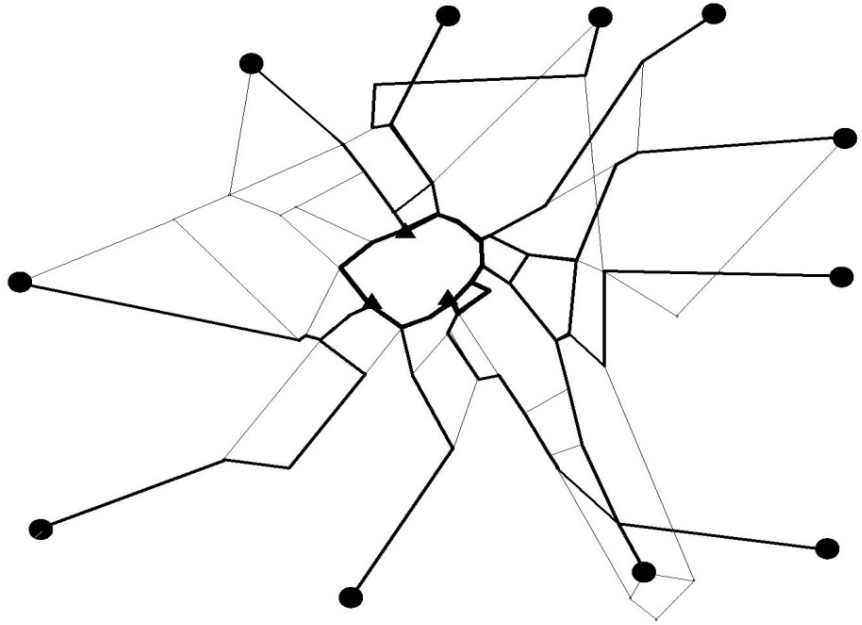
Introduction

Small-medium size cities as urban centers with a population of few hundred thousand inhabitants and restrained spatial dimensions



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Introduction

Land use characteristics:

- small (historic) center
- radial structure for the other neighborhoods

Mobility system characteristics:

- trips have a widespread in origin
- trips are concentrated in few major points of attraction located in the city center
- the road network is spread radially
- public transport only by buses with no lines of different types

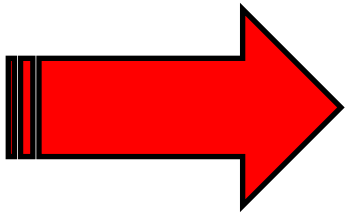
Background

TND COMPLEX and NON-CONVEX PROBLEM

Solution methods:
Heuristics procedures
Meta Heuristics algorithms

Target:
Many-to-many context

Applicability:
In some cases difficult for real network size problem



Solution method proposed:
Polynomial heuristic

Target:
Many-to-few context

Applicability:
Easy and adaptable

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Problem definition

Optimization problem with objective function taking into account the impacts of transport on the various stakeholders (operators and users)

$$C_1 \sum_{i \in I_i} L_i \cdot f_i + C_2 \sum_{i \in I_i} \sum_{hk \in I_{a,i}} tp_{hk,i} \cdot f_i + C_3 nb + C_4 \sum_{i \in I_i} \sum_{hk \in I_{a,i}} tp_{hk} \cdot p_{hk,i} + C_5 \sum_{i \in I_i} \sum_{hk \in I_{a,i}} ta_{hk,i} \cdot pa_{hk,i} + C_6 \sum_{n \in I_n} nt_n$$

1) total traveled distance (in space)
2) total traveled distance (in time)
3) number of used buses

4) total users' in-vehicle time
5) total users' waiting time
6) total number of transfers

Problem definition

Data:

- O/D Matrix
- Road network
- Starting number of central and external terminals
- Buses capacity

Variables:

- Routes
- Frequencies

Constraints:

- Level of demand to be served
- No more than one transfer
- All lines have to reach all central attractors
- Avoid circuit
- Route length
- Maximum load factor

Solving procedure

The problem involves a simultaneous and combined solution of vehicle routing, assignment, facility location, lines' recombination and scheduling problems

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Heuristic procedure

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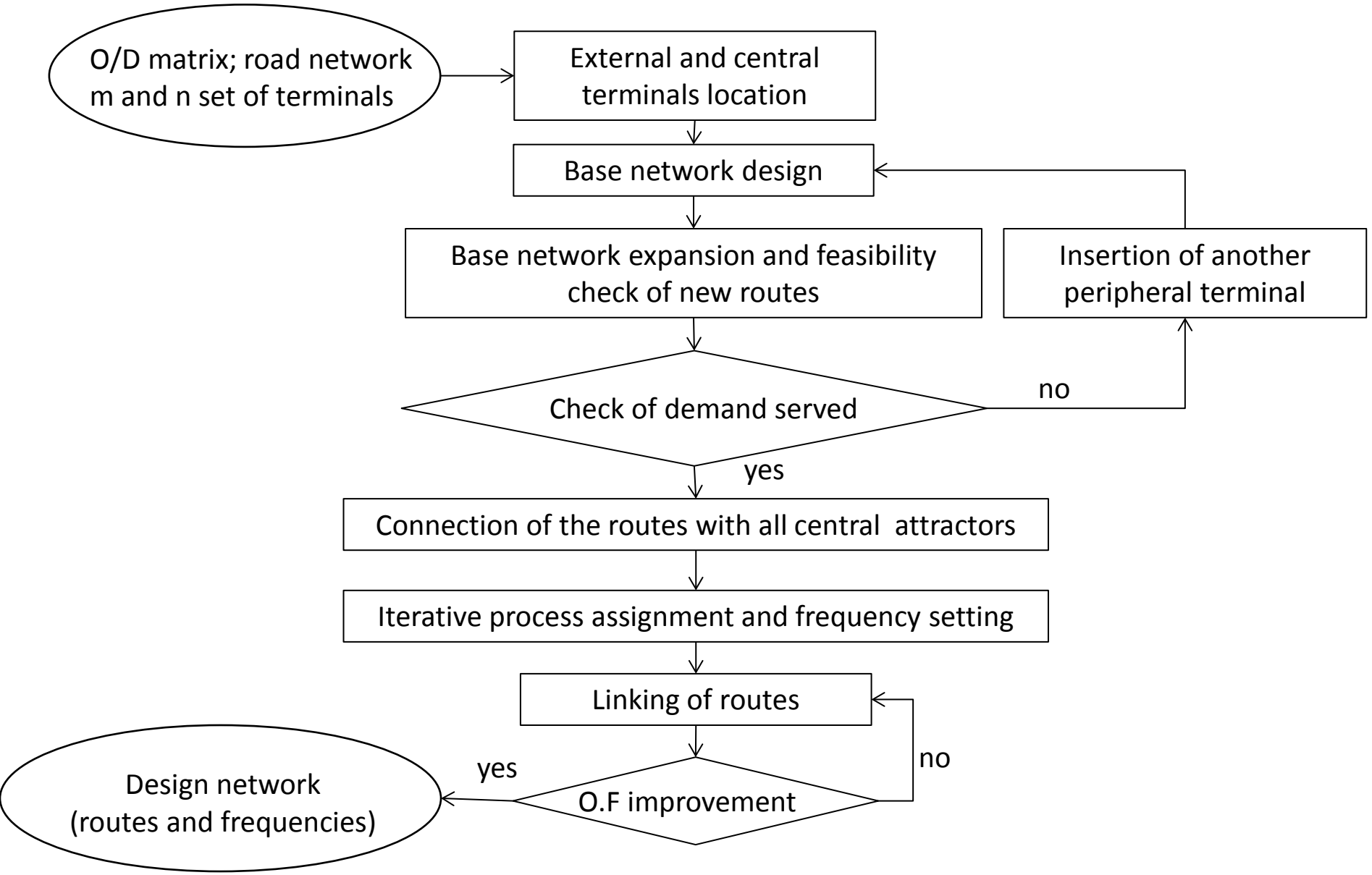
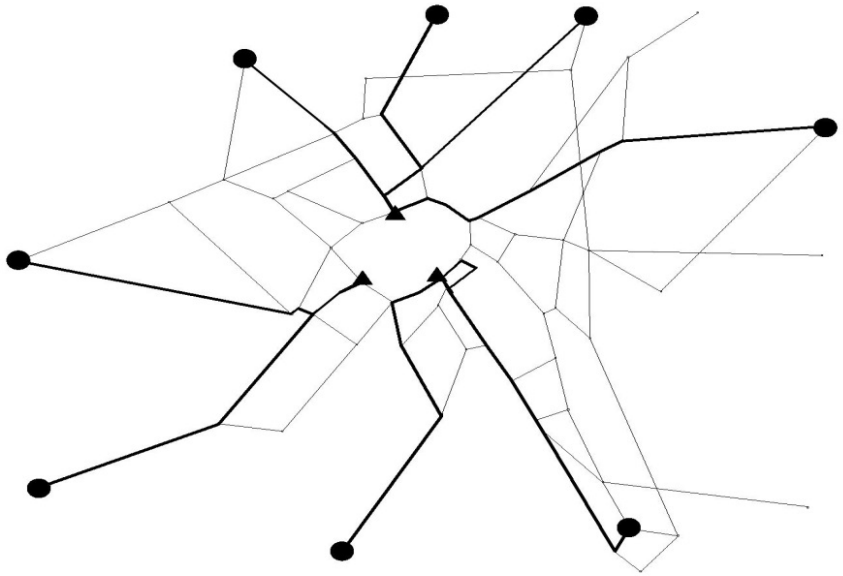
Practical and fast algorithm to offer solution that are better than current practices


O/D matrix; road network
m and n set of terminals
External and central terminals location
Base network design
Base network expansion and feasibility check of new routes
Insertion of another peripheral terminal
Check of demand served
no
yes
Connection of the routes with all central attractors
Iterative process assignment and frequency setting
Linking of routes
O.F improvement
yes
no
Design network
(routes and frequencies)

Location of terminals

- Identify main points of attraction and generation
- Localize terminals in peripheral nodes
- Localize temporary terminals in central nodes



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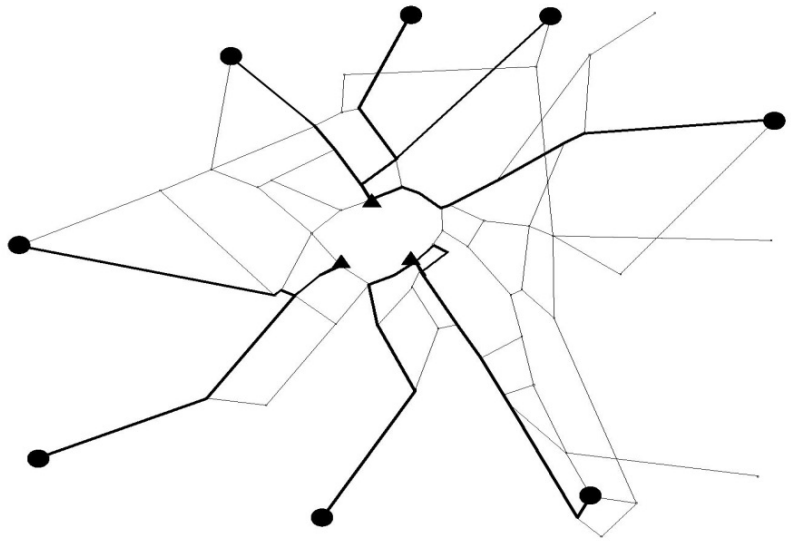
Base network definition

- selection of an external terminal
- generation of *m* paths from the selected external terminal to each of the central ones
- Selection of the shortest path among all the *m* generated ones

Operation repeated for all external terminals



Expansion of the base network (1)

Systematic procedure of route modifications for each previously generated routes:

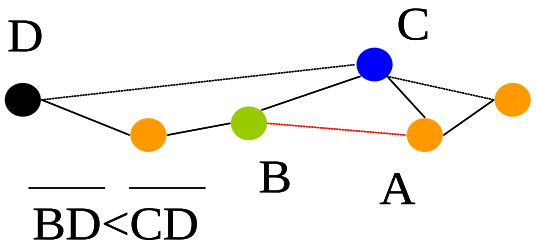
- increase of a prefixed value (e.g. +50%) of travel cost of selected link
- compute new shortest path between endpoints of selected link
- check about feasibility of new route

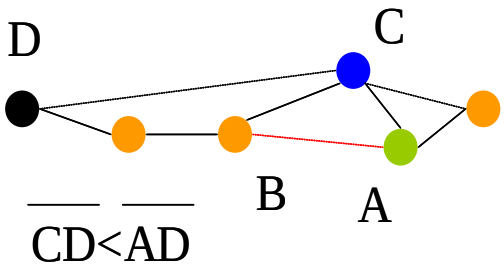
Several possible criteria for selection of links to be eventually replaced:

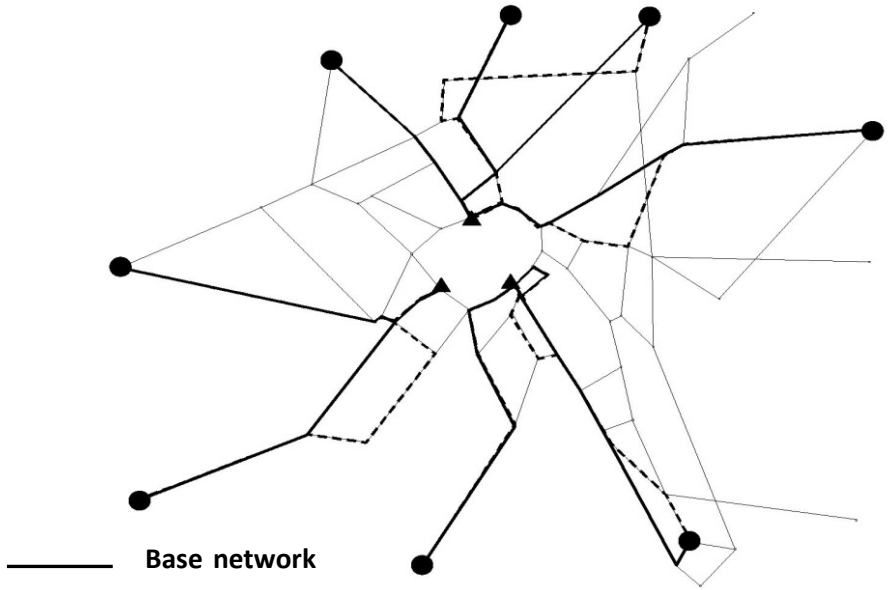
1) in a sequential way by analyzing, route by route, all the links
2) selection among all links starting from the one characterized by the minimum level of passengers

Feasibility criteria for Expansion of the base network

- serve new demand
- increase in length less than a threshold value
- modification rational in terms of route alignment







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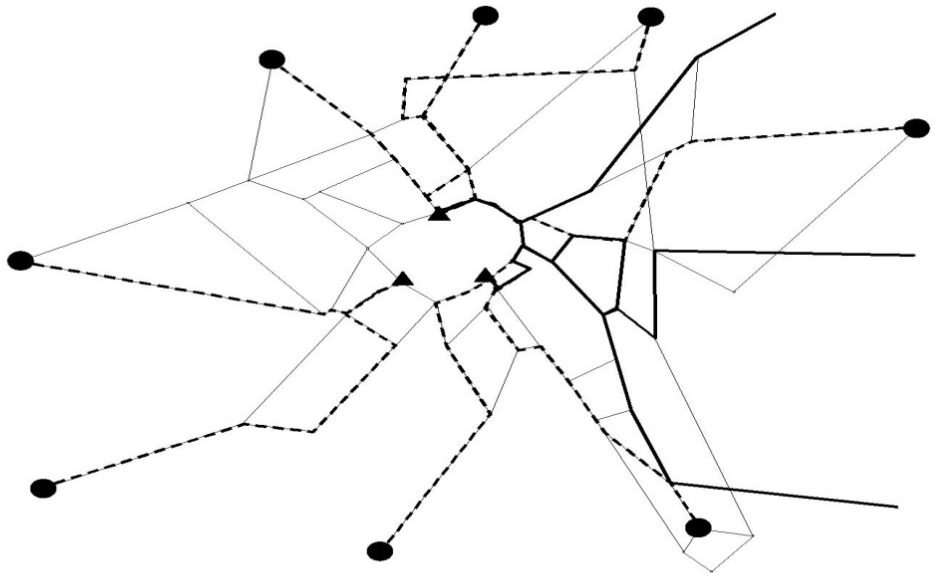
Check of demand served

Check of the level of trips served after expansion phase of base network

$$\sum_{hk \in I_a} pa_{hk} - \sum_{n \in I_n} nt_n \geq x \sum_{ij \in I_{OD}} s_{ij}$$

Otherwise……..
Selection of a new additional external terminal and start again procedure (base + expansion phase)

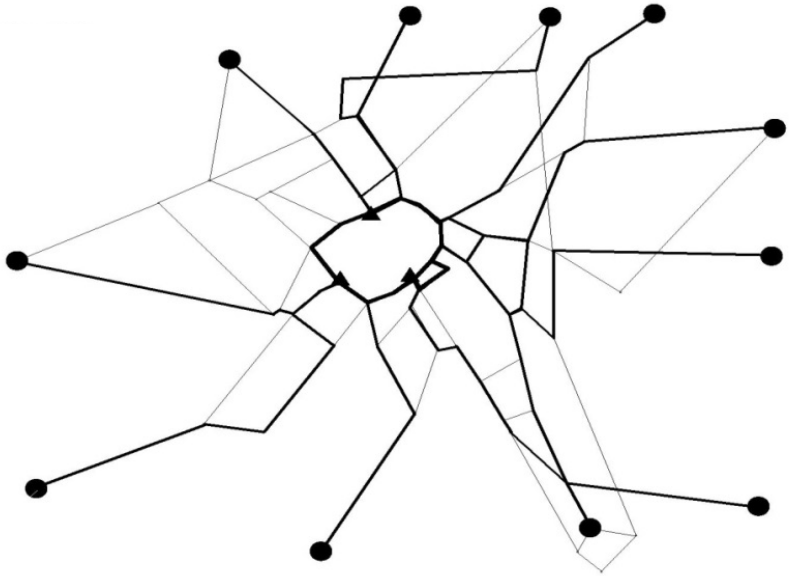


Connecting routes to all central attractors

Operation repeated for each route

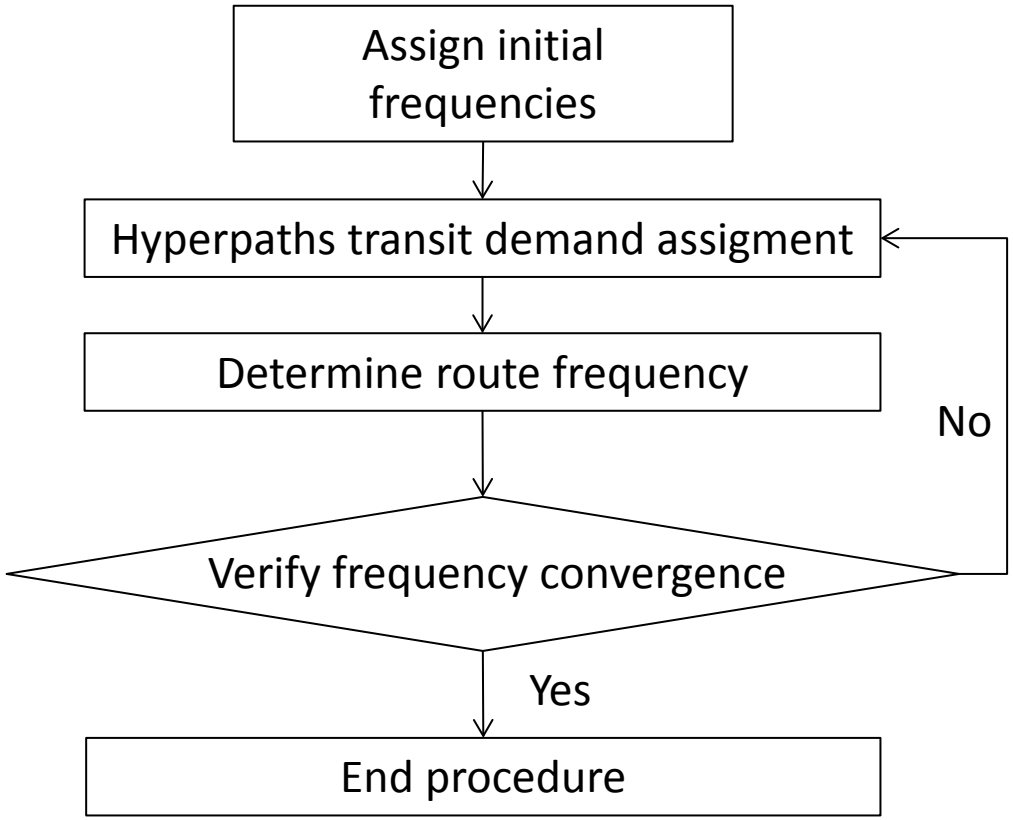
- Extending route to other central attractors not previously reached
- Extending direction corresponding to the minimum total travel time of passengers

$$\min \sum_{hk \in I_{a,i}} tp_{hk,i} \cdot p_{hk,i}$$



Assignment and frequency setting process

$$f_i = \frac{p_{\max}}{fc_{\max} \cdot C_V}$$



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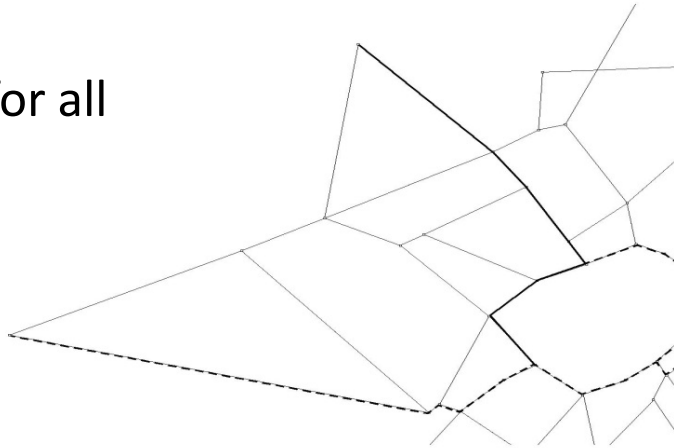
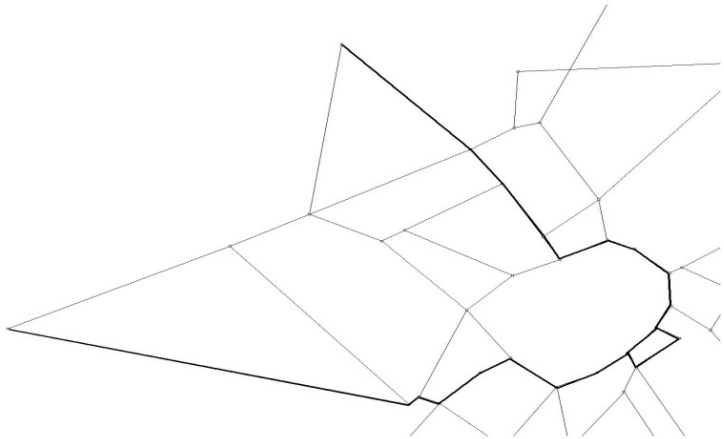
Linking of routes

- selection of line with the greatest number of runs
- assessment of the paths followed by the passengers of selected line
- identification of the lines to or from which a transfer takes place
- for each of identified lines, computation of number of runs
- linking of routes carried out if number of runs ≥ 1

$$C_i = \left\lfloor \frac{n_i}{\sum_{i \in I_{id}} n_i} \cdot C_s \right\rfloor$$

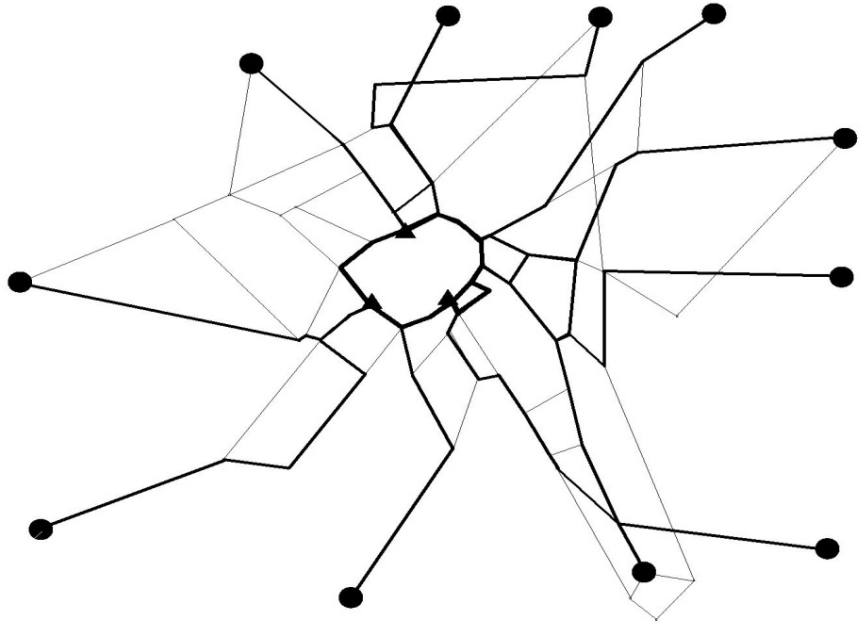
Operation repeated for all routes





Numerical application (1)

Foligno 60.000 inhabitants
Public transport demand 3,000 trips/hour with 16 lines



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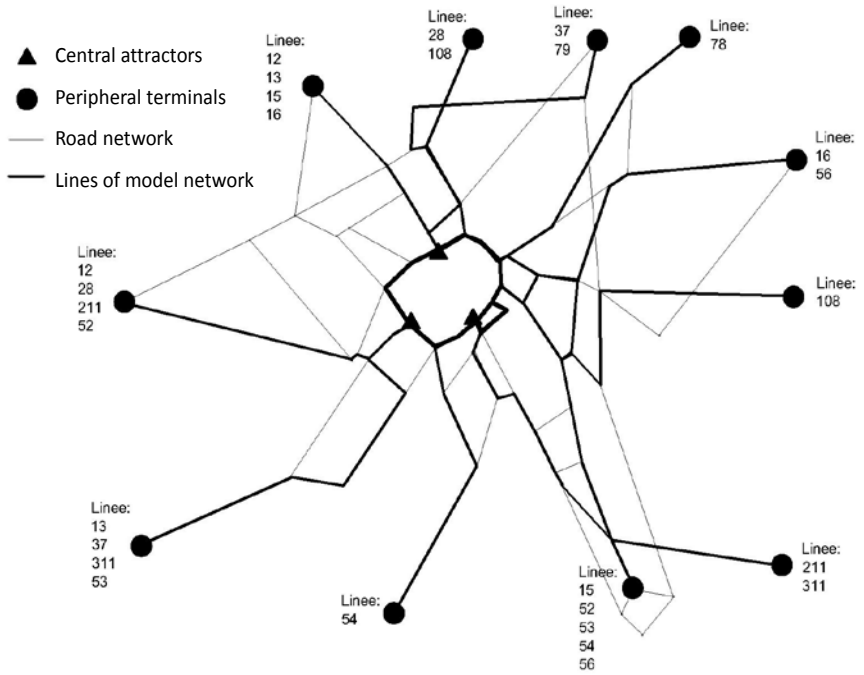
Numerical application (2)



Indicator	Existing Network (a)	Base Network (b)	Final Network (c)	Difference (%) (b-c)	Difference (%) (c-a)
Number of lines	16	11	14	+21%	-12%
Buses-km	347	375	348	-7%	0%
Buses-h (min)	1015	1040	975	-6%	-4%
Number of buses	23	22	23	+4%	0%
Number of transfers	2710	1.260	860	-32%	-68%
Total in vehicle time (min)	33940	32625	32935	+1%	-3%
Total waiting time (min)	39460	37640	34310	-9%	-13%
Avg load factor	0.42	0.39	0.42	+8%	0%

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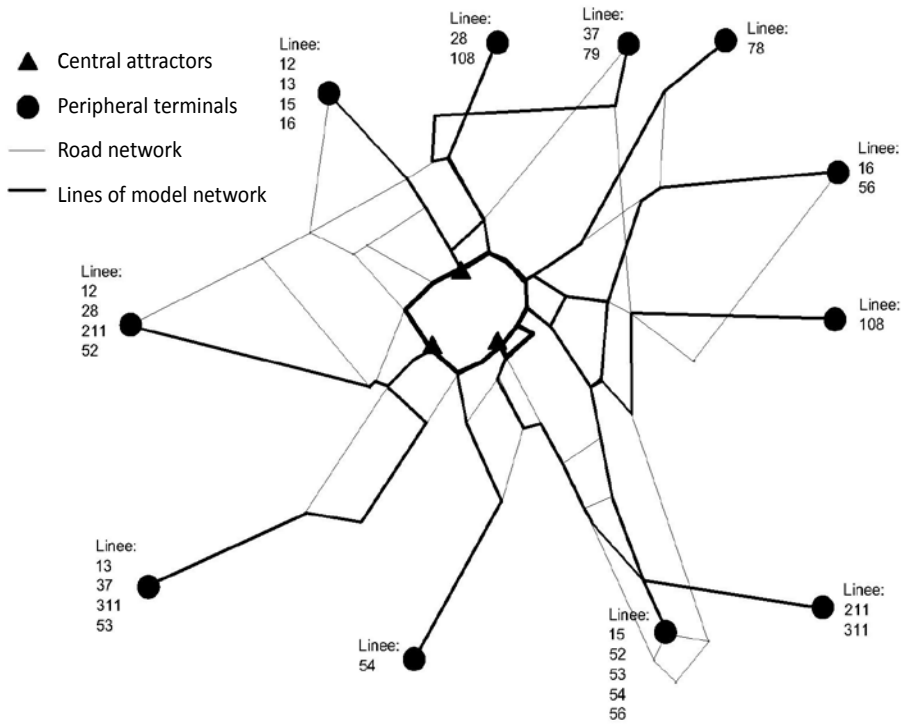
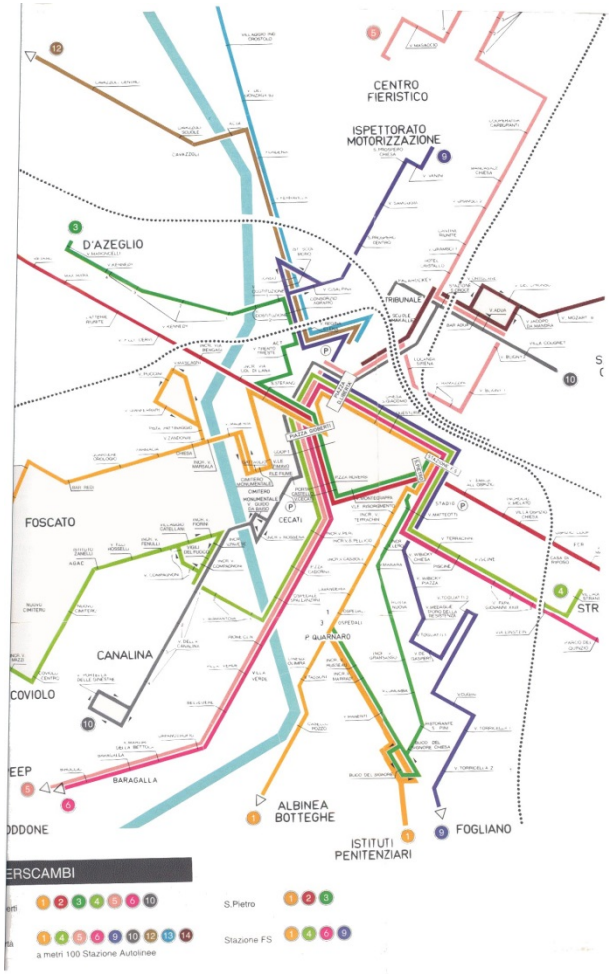
Numerical application (3)





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Conclusions

Pros:

- Promising performance and intuitive procedure
- Remarkable ease of execution on real size network
- Easy control of operation by designer

Cons:

- Deterministic procedure
- Dependence on initial set of choice
- Dependence on link enumeration criteria

Further developments

- Use of different link enumeration criteria and/or constraint relaxation
- Use of different criteria for linking lines phase
- Stochastic optimization and multi-criteria design
- Time dependence procedure (peak-hour, off peak-hour, scheduling)

Testing and comparing the proposed procedure towards optimal values computed for small enough case studies

Testing the proposed procedure to solve much larger size cities