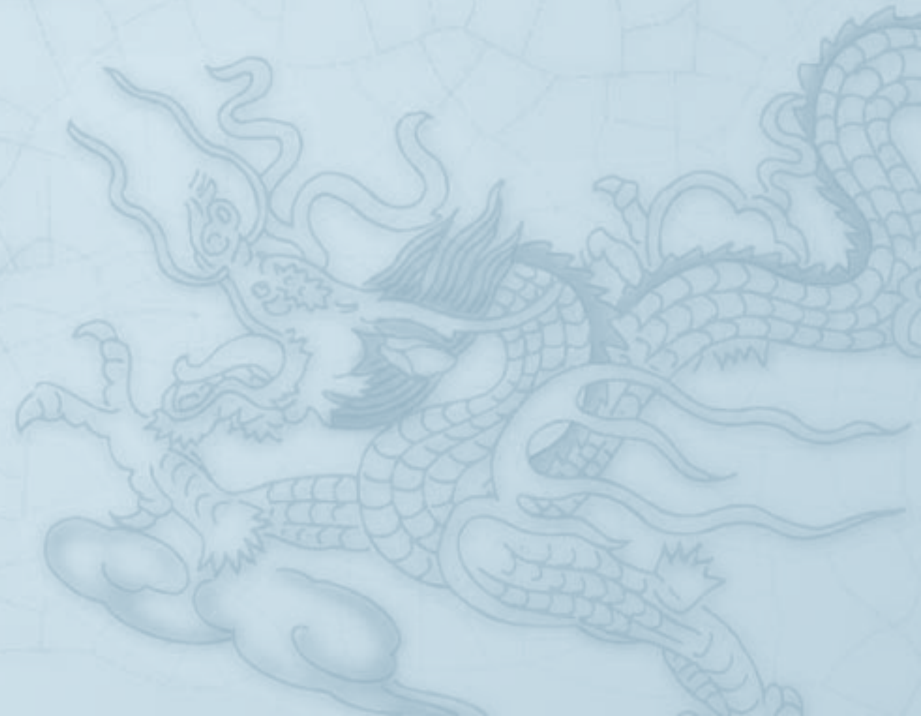


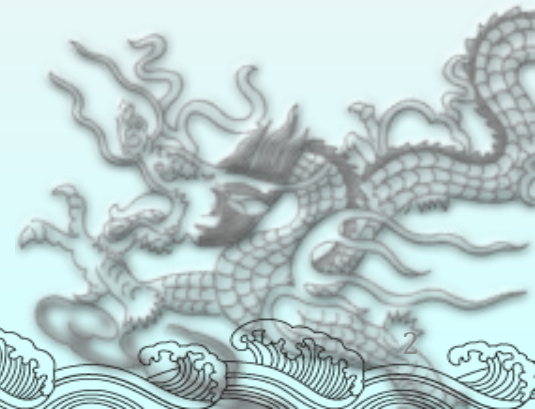
A Stop-based Bus Route Network Optimization Under Multi-modal Transit Development

Zhengdong HUANG
School of Urban Design
Wuhan University



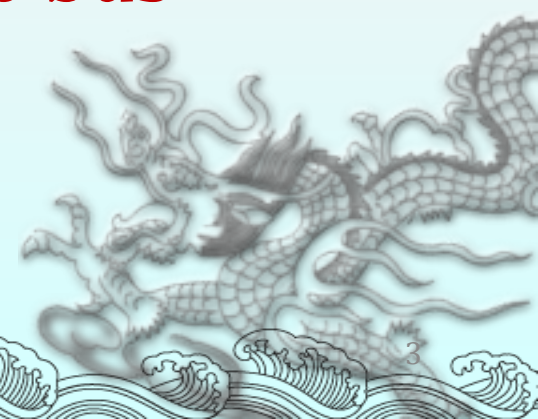
Contents

- ◆ Introduction
- ◆ GA in TNDP
- ◆ A stop-based approach
- ◆ An experiment with two scenarios
- ◆ Result and analysis
- ◆ Conclusions



Motivation

- ◆ Traditional bus network
 - ◆ Rail routes being constructed
 - ◆ Bus routes needs to be adjusted when rail route put into operation
 - ◆ A dynamic adjusting process
- looking for a method to optimize bus network during rail construction



Levels of tasks in transit planning

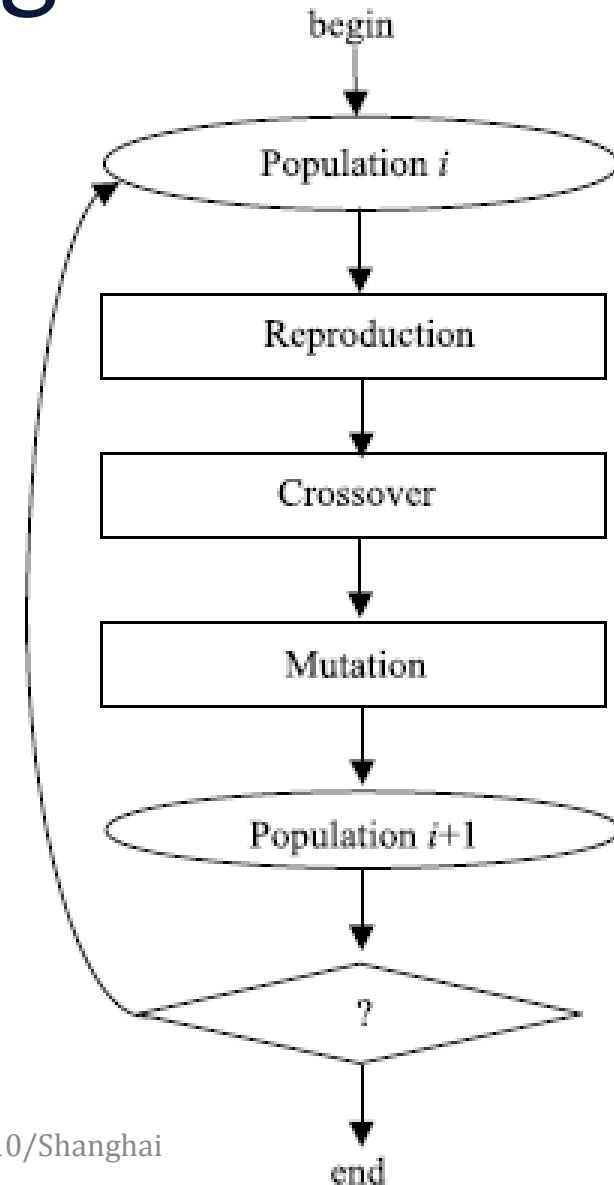
- ◆ Five levels (Ceder & Wilson, 1986)
 - ◆ **network** design (route performance indicator)
 - ◆ **frequencies** setting
 - ◆ **timetable** development
 - ◆ **bus scheduling**
 - ◆ **driver scheduling**
- ◆ This study: **network design** – TNDP (route performance indicator)

The TNDP

- ◆ The transit network design problem (TNDP)
 - ◆ Aims at creating a set of bus routes under a set of objectives and constraints
- ◆ Mandl (1979) 's work starting with an empty routes network
- ◆ TNDP is confronted with conflicting interests: the transit users, operators and the city governor

Genetic Algorithm

- ◆ GA is applied to solve Combinatorial Optimization
 - ◆ Population
 - ◆ Individual
 - ◆ Chromosome/string
- ◆ TNDP
- ◆ Bus scheduling



Characteristics of GA

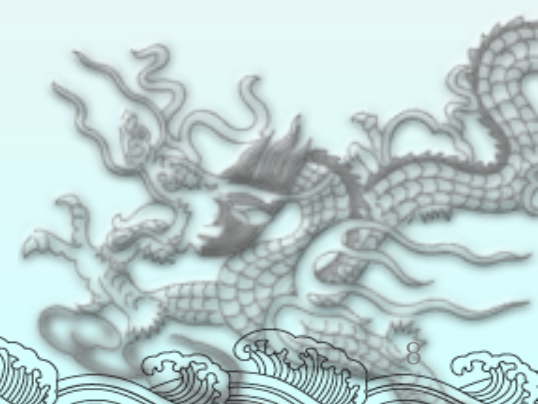
- ◆ Objective form: **goodness** or **fitness function**
- ◆ **Probabilistic transition rules**,
NOT deterministic rules
- ◆ It may incorporate **problem-specific information and expertise** during the optimization process.

(Chakroborty, 2003)

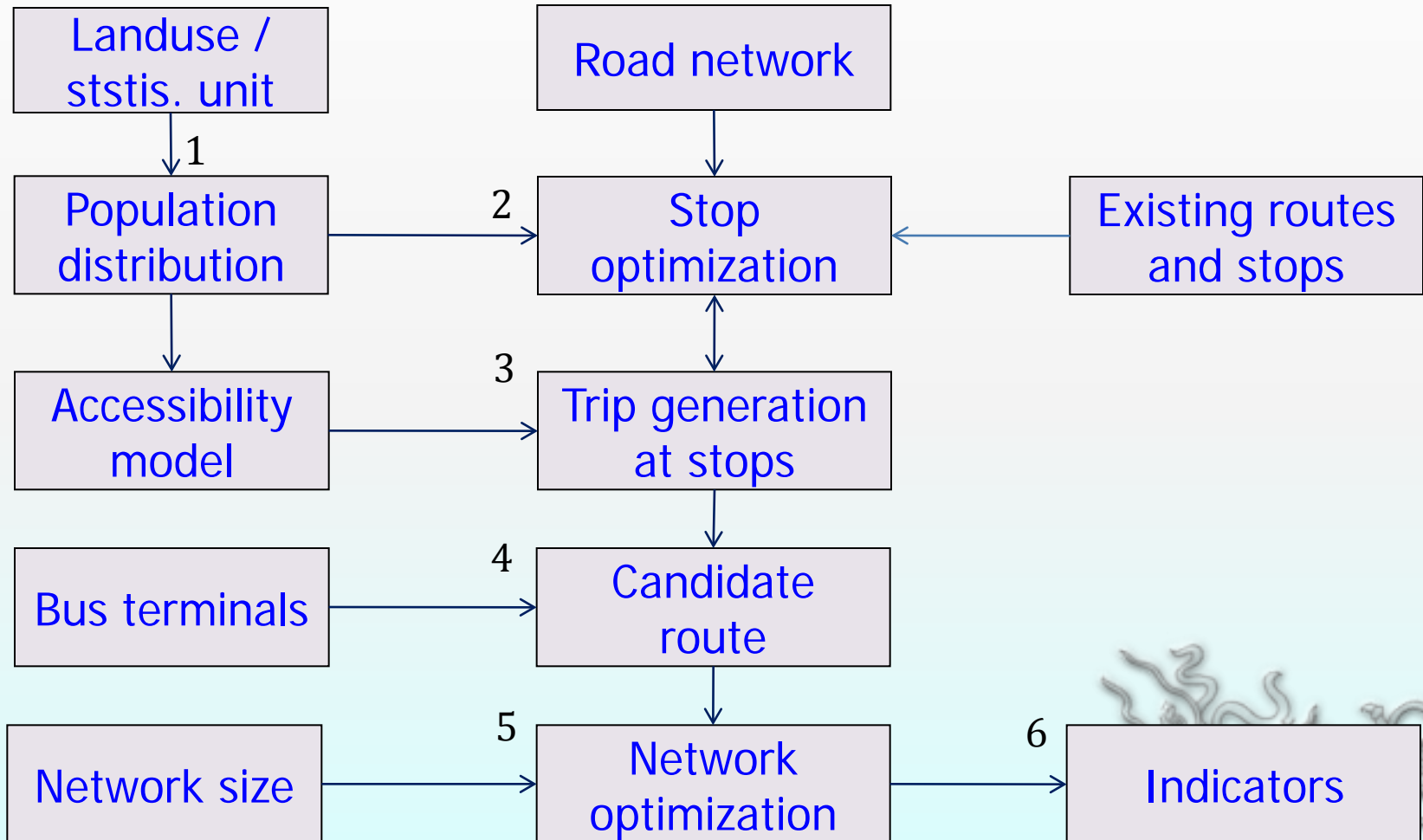


Bus network optimization

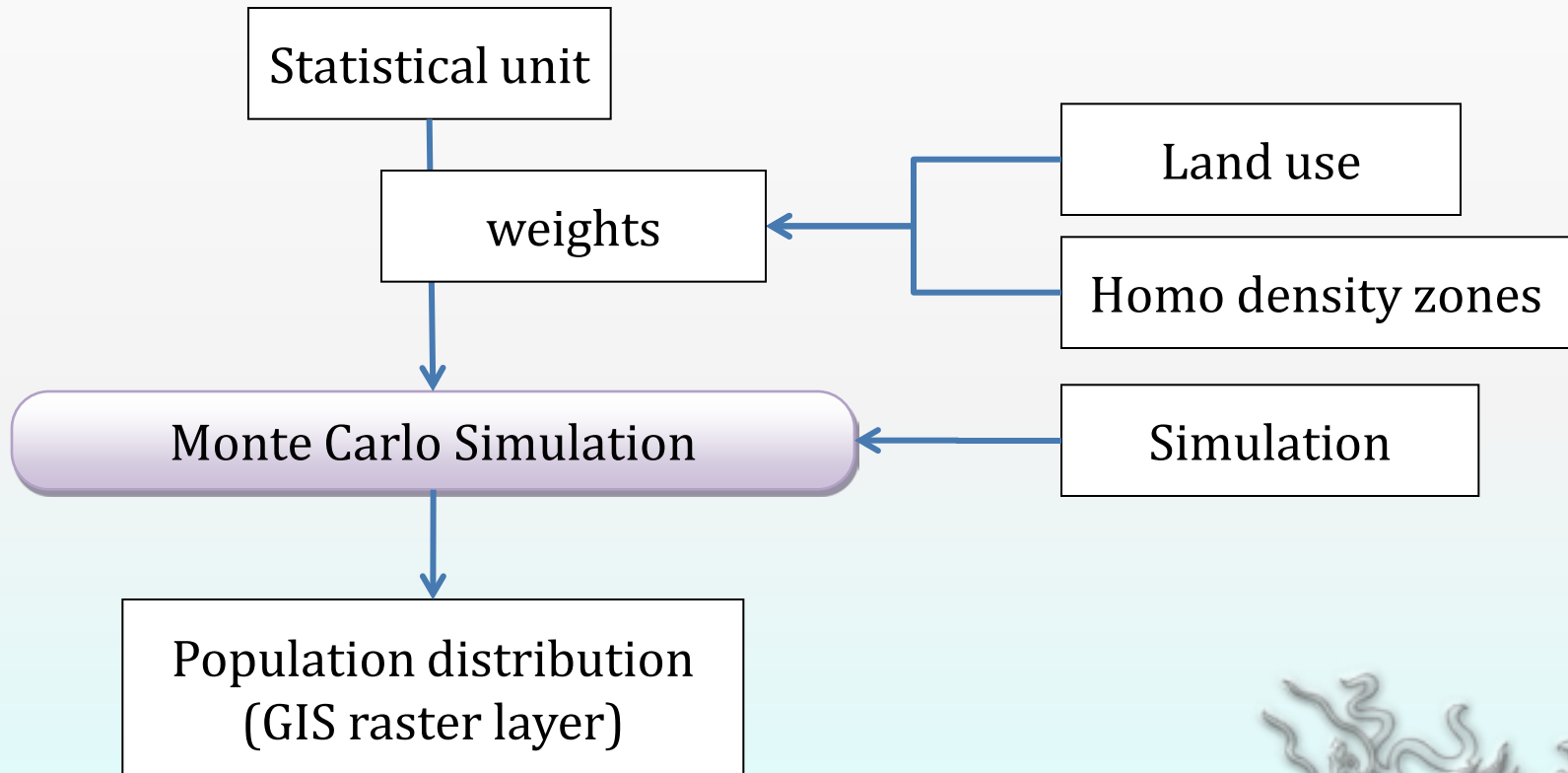
- ◆ A TNDP
- ◆ A optimization process using GA
- ◆ Features:
 - ◆ A given set of bus terminals
 - ◆ Candidate routes computed for terminal pairs
 - ◆ Select a set of routes from many candidates
 - ◆ Existing routes are acknowledged
 - ◆ Integration with rail network



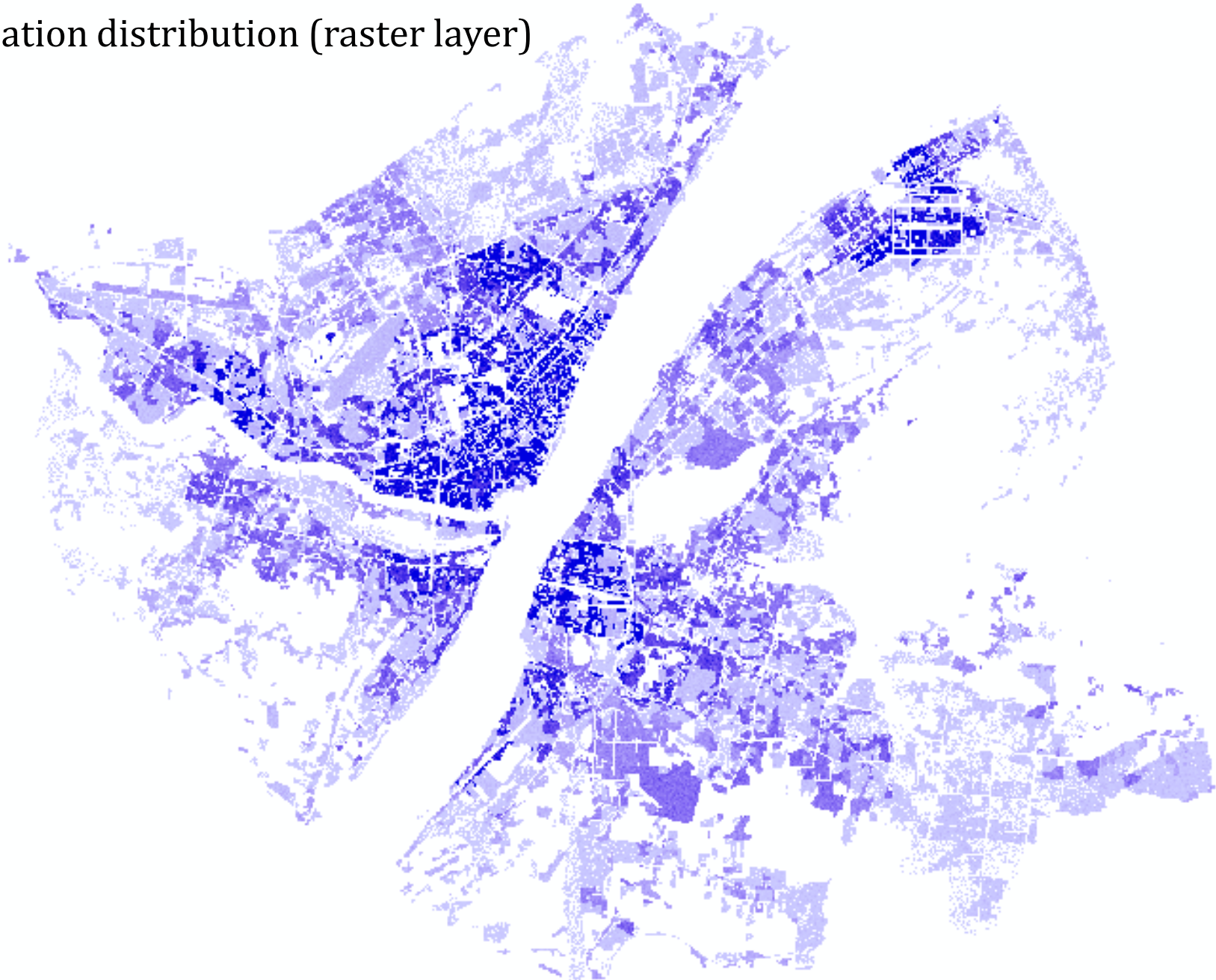
General framework



Deriving population distribution

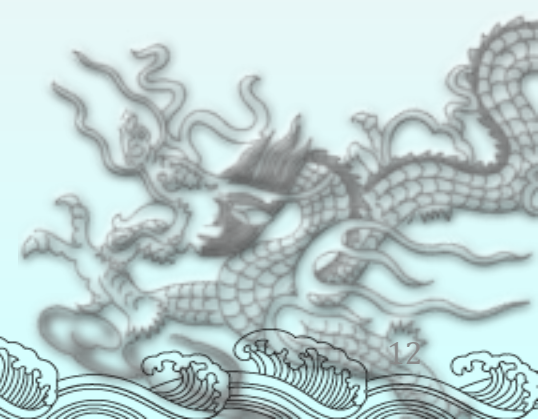


Population distribution (raster layer)

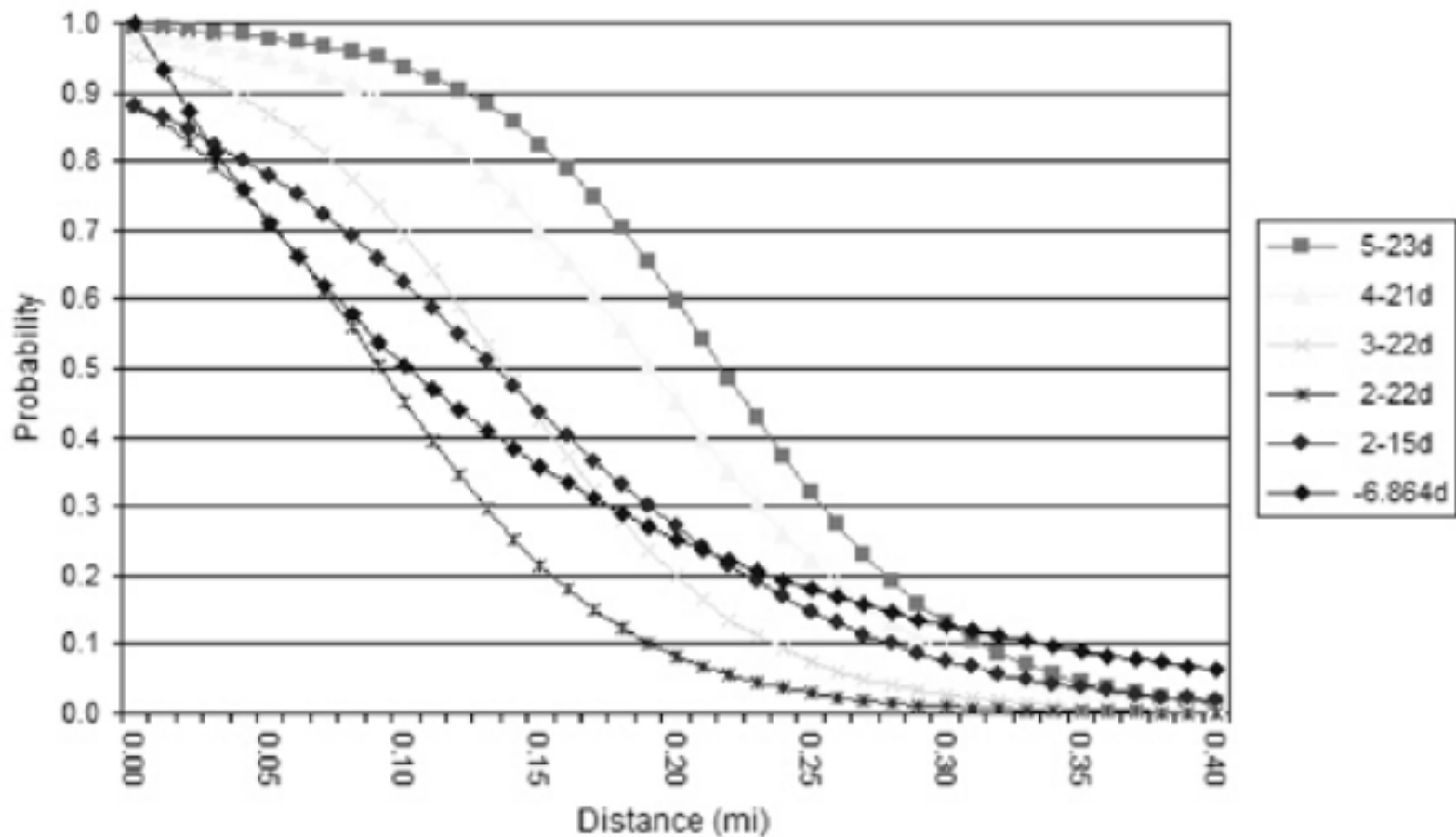


Trip Generation at bus stops

- ◆ An accessibility based approach
- ◆ Implemented in GIS
- ◆ Trip generation = production + attraction
 - ◆ Trip production from disaggregated population data
 - ◆ Trip attraction from land use and total production



Distance decay functions



Distance decay function

Negative logistic function

$$p = e^{a-b*d} / (1 + e^{a-b*d})$$

Parameters:

Using miles as unit, $a=2$, $b=15$

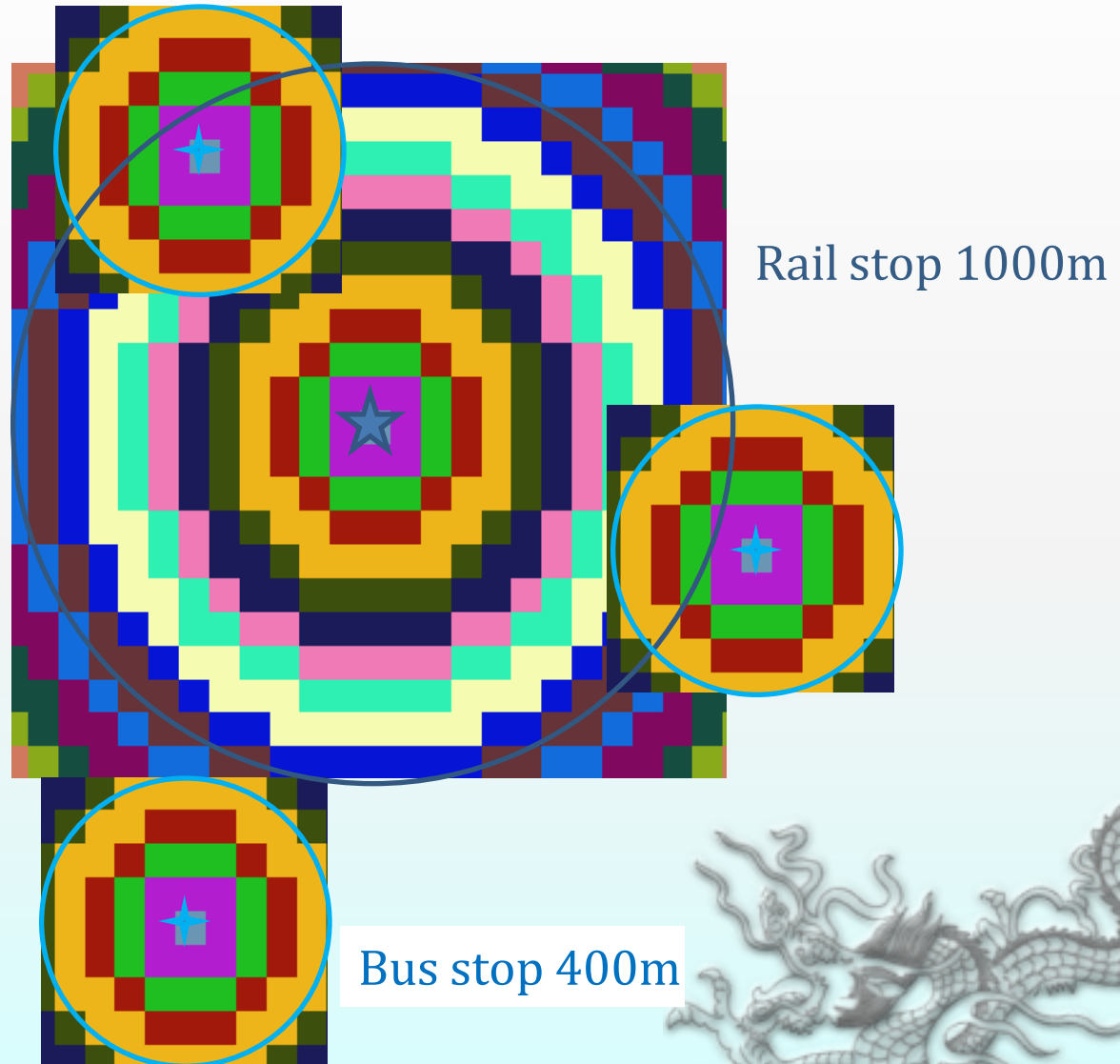
Using meters as unit, $a=2$, $b=15/1600=0.0093$

Kimble et al, 2006

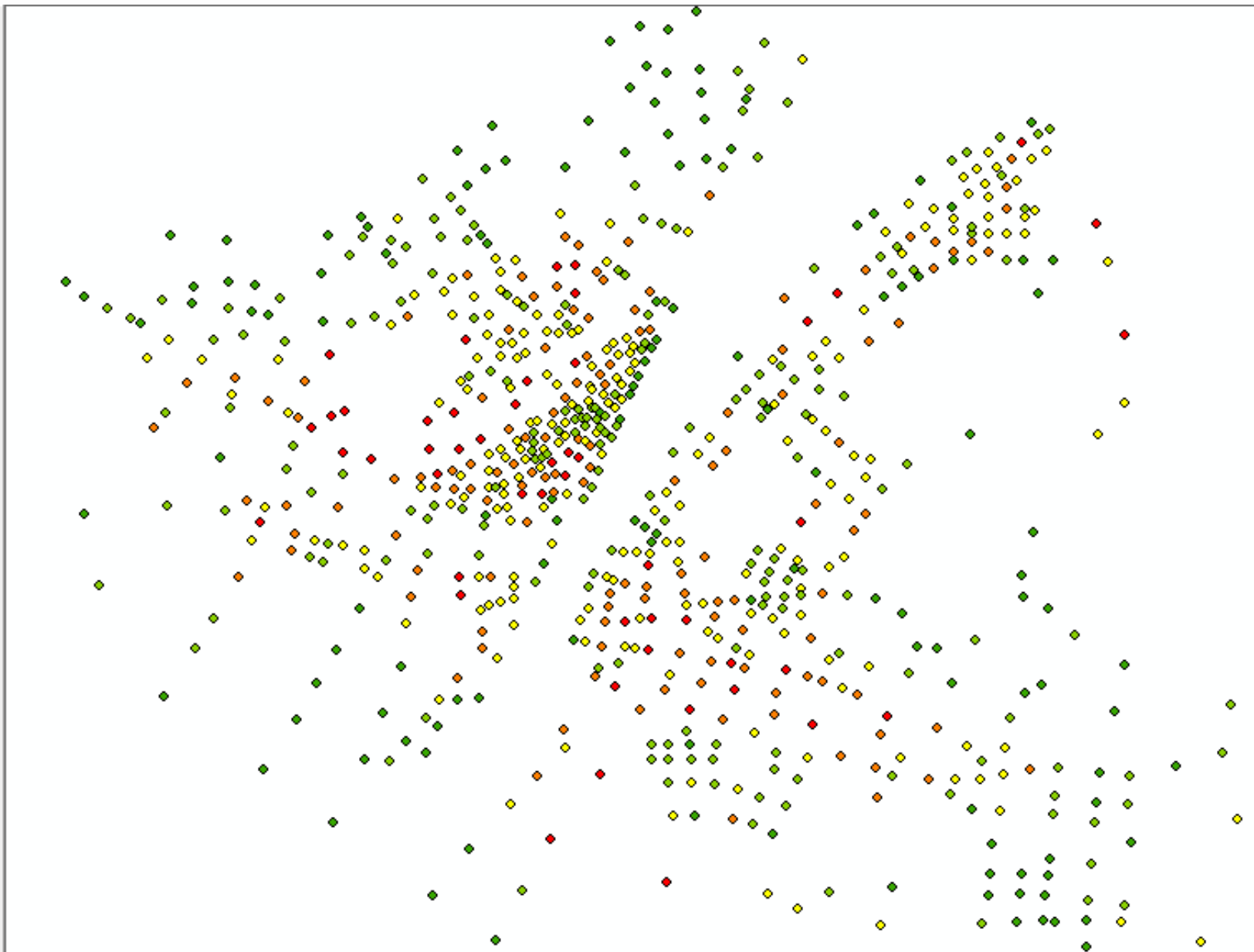
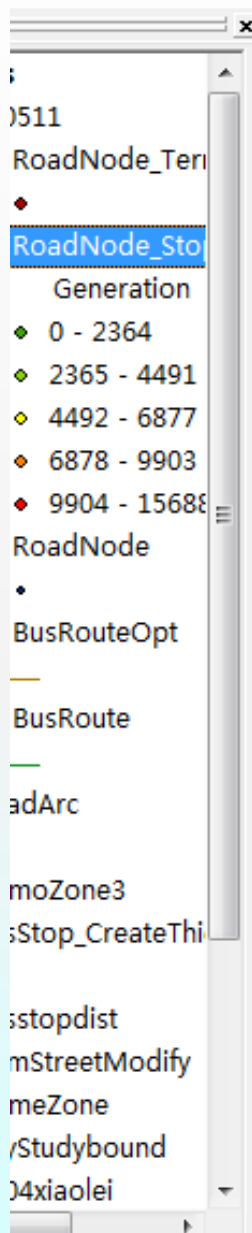
Estimate transit trip production

To calculate trip generation at stops based on accessibility model

- Rail stop → bus stop
- Spreading
- Overlapped cells



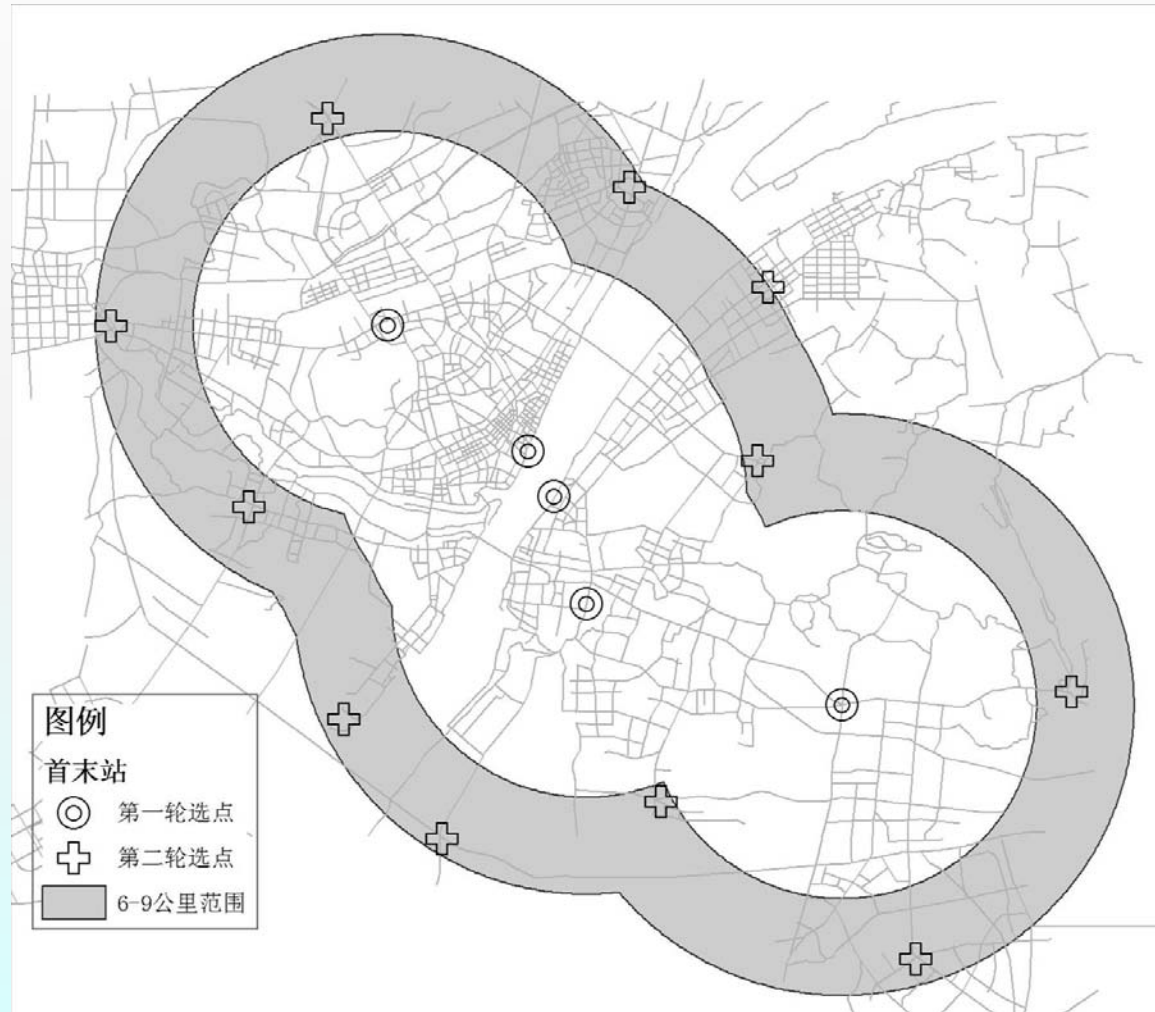
Classification of stops based on trip production



Identifying bus terminals

- ◆ A pragmatic process
- ◆ Intercity transport centers (rail, water, land), conventional activity centers, urban fringe areas are important sites
- ◆ They form a tessellation of urban space
- ◆ Serve as starting criteria, but their locations may be changed in real deployment

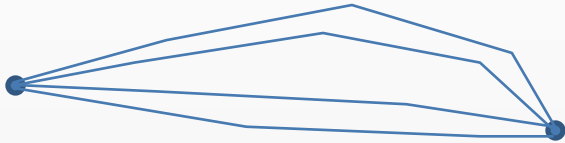
Identifying bus terminals with GIS



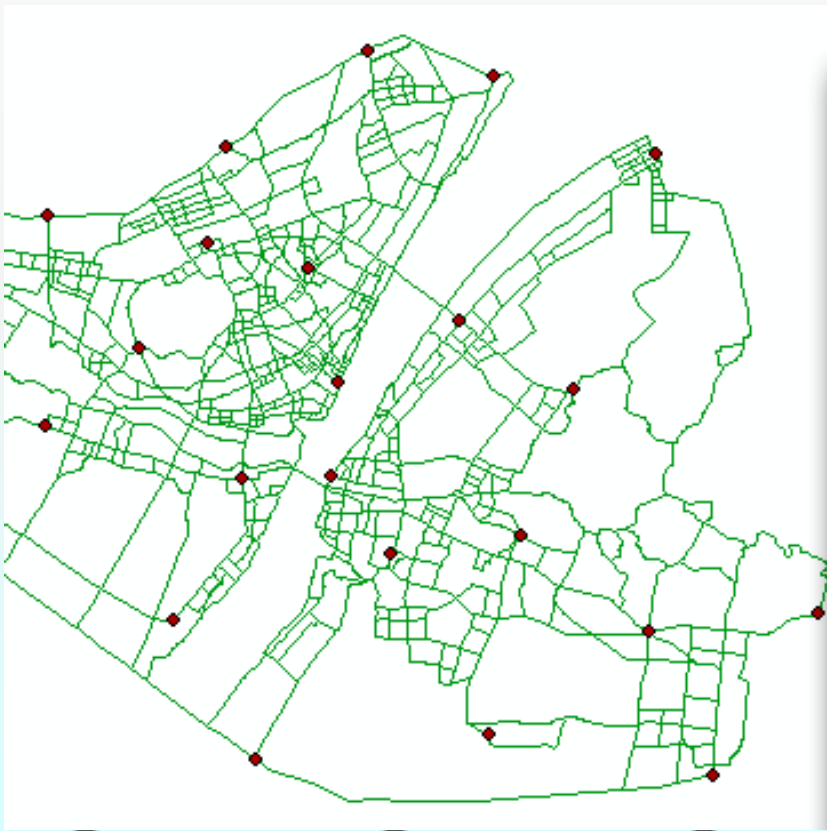
Candidate bus routes

- ◆ Candidate routes for optimization
- ◆ Multiple candidate routes between each pair of bus terminals
- ◆ Candidate route should satisfy a set of criteria

Multiple routes



Each terminal pair has k candidate route
But finally only one will be selected



OBJECTID	SHAPE *	RouteID	Kth	FromTer	ToTerm	NrOfSto
57639	Polyline	1	1	140	141	20
57640	Polyline	2	2	140	141	19
57641	Polyline	3	3	140	141	20
57642	Polyline	4	4	140	141	19
57643	Polyline	5	5	140	141	20
57644	Polyline	6	6	140	141	19
57645	Polyline	7	7	140	141	21
57646	Polyline	8	8	140	141	20
57647	Polyline	9	9	140	141	21
57648	Polyline	10	10	140	141	20
57649	Polyline	11	1	140	145	13
57650	Polyline	12	2	140	145	13
57651	Polyline	13	3	140	145	10
57652	Polyline	14	4	140	145	10
57653	Polyline	15	5	140	145	13
57654	Polyline	16	6	140	145	10
57655	Polyline	17	7	140	145	14
57656	Polyline	18	8	140	145	11
57657	Polyline	19	9	140	145	15

Multiple candidate routes between terminals

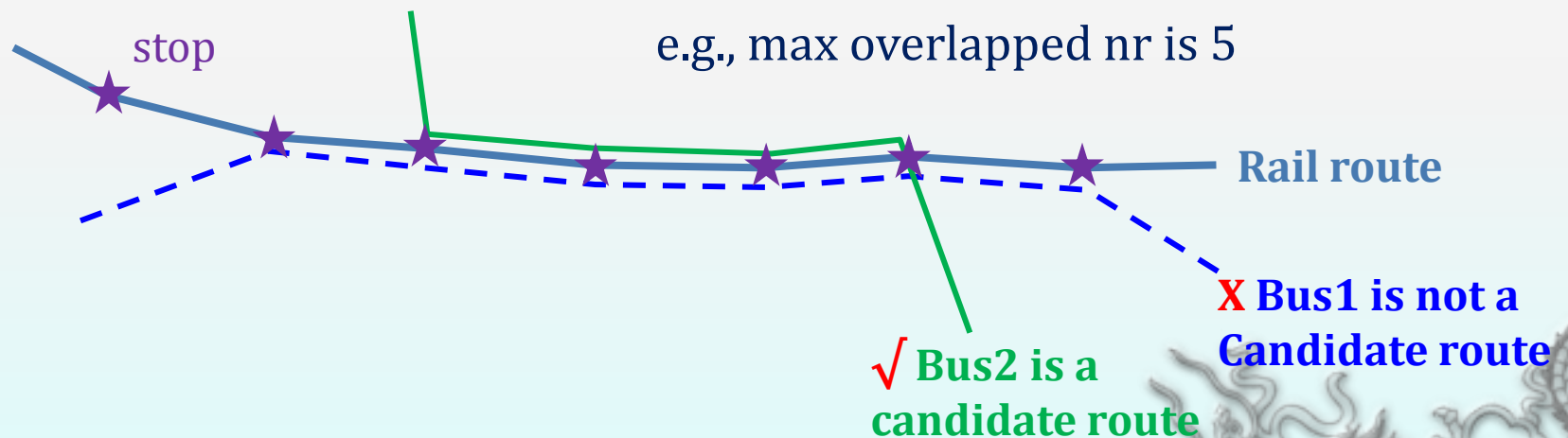
- ◆ K-shortest path search
 - ◆ n terminal pairs
 - ◆ n x k candidate routes in total
- ◆ A valid route should satisfy:
 - ◆ Length between, e.g., 5-28 km for Wuhan
 - ◆ Minimum number of stops, e.g., 6
 - ◆ Overlap with rail routes, e.g., 5 overlapped stops
 - ◆ Production - attraction balance
$$w=1-\text{Abs}(P-A)/(P+A)$$
a route with small w is not a valid route
- ◆ Final candidate routes $m \times j \leq n \times k$ ($m \leq n; j \leq k$)

Parameters for candidate routes

Category	Parameters	Default value
candidate route creation	Route length (min)	5
	Route length (max)	20
	Number of stops (min)	6
	Passenger flow per day (min)	1000
	Route efficiency value (min)	0.1
	Multiple routes for each pair (k)	8
	Max Nr of Overlap stops with rail route	5

Criteria for overlapped routes

- ◆ Bus route and rail route should not overlap
- ◆ Criteria: maximum overlapped stops



参数设置

K值 最大距离 最小距离 最少站点数

线路最大非直线系数 线路最小效益值 线路最小公里客流量

站点对选择
选定站点对

selected

	FromTerminal	ToTerminal	长度	最少站点数
<input checked="" type="checkbox"/>	252	6	11382.4...	7
<input type="checkbox"/>	252	24	17282.9...	17
<input type="checkbox"/>	252	48	13211.4...	13
<input type="checkbox"/>	252	49	6274.57...	5
<input type="checkbox"/>	252	223	10634.0...	19
<input type="checkbox"/>	252	112	8560.12...	8
<input type="checkbox"/>	252	295	12100.0...	23
<input type="checkbox"/>	252	376	5860.43...	12
<input type="checkbox"/>	252	141	5542.77...	7

被筛选站点对

removed

	FromTerminal	ToTerminal	长度	最少站点数
<input checked="" type="checkbox"/>	252	328	24421.0...	33
<input type="checkbox"/>	252	140	19494.9...	24
<input type="checkbox"/>	252	719	5442.82...	4
<input type="checkbox"/>	252	946	27783.8...	36
<input type="checkbox"/>	252	983	20824.5...	28
<input type="checkbox"/>	252	1121	26441.9...	33
<input type="checkbox"/>	252	1176	20742.7...	21
<input type="checkbox"/>	252	1188	32435.3...	39
<input type="checkbox"/>	252	1210	31963.0...	39

>>

<<

重置

现有线路

Existing routes

当前选定站点对数 225

FromTerminal	ToTerminal	长度	站点数	P	A	W
140	141	15293.9704336301	21	60671	84622	0.8351537926...
141	983	18178.8130546885	27	68033	111364	0.7584630735...



Constructing optimal route network

- ◆ Identify max number of bus routes T
- ◆ Select T routes from $m \times k$ candidates
- ◆ A genetic algorithm
- ◆ Fitness function:
$$(\max) y = a * \sum w + b * \text{stopcov}$$

$\sum w$: total w for all selected routes
stopcov: percentage of stops included
- ◆ Some other fitness functions may also apply

Parameters for GA

Category	Parameters	Default value
GA	Max number of routes	280
	Population size	40
	Crossover probability	0.7
	Mutation probability	0.1
	Maximal generations (loops)	8000
	Efficiency weight	0.2
	Coverage weight	0.8

Structure of an INDIVIDUAL(solution)

CR: Candidate Route

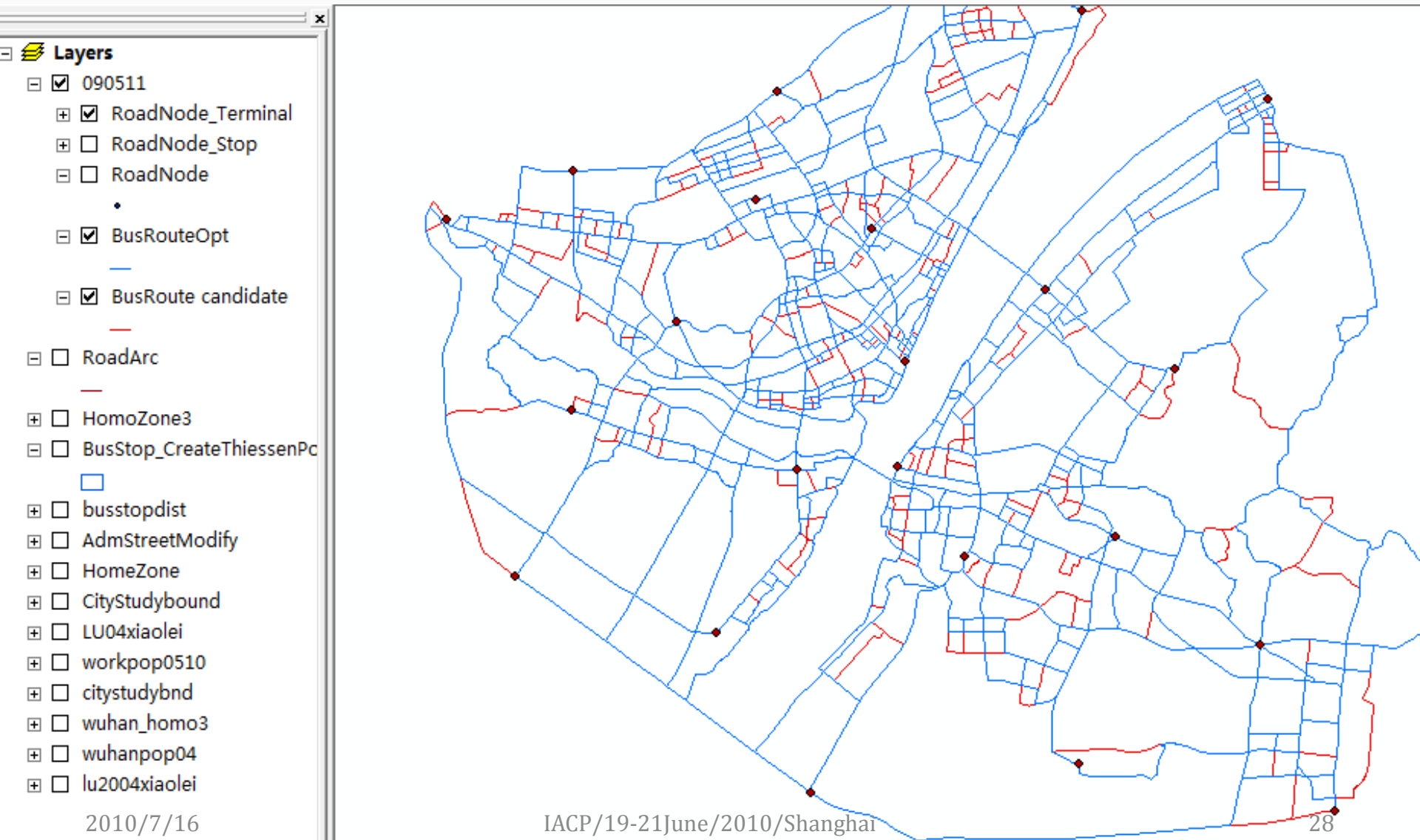
		CR1	CR2	CR3	CR4	...	CRk
Terminal pairs	1	1	0	0	0		0
	2	0	0	1	0		0
	...						
	T	0	0	1	0		0

$T \leq M$

1 = selected into the individual

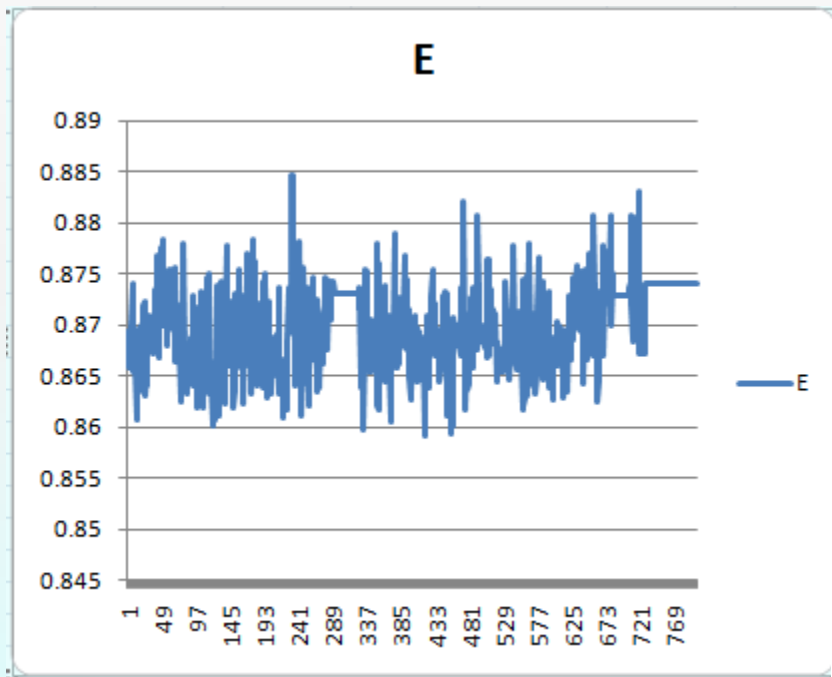
If $T > M$, $T = M$

Candidate routes and final network

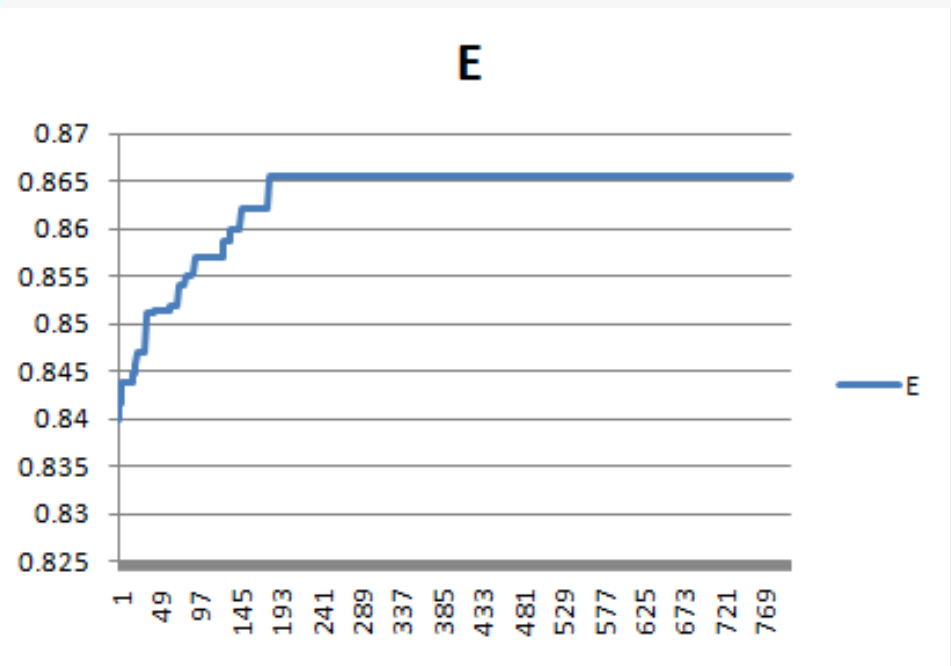


Fitness function

Best individual in each generation



the best individual of all generation
(elite keep)



Data set



Short-term and long-term rails



Current bus network

线路总长 (km)	Total bus route length (km)	3164
线网密度 (km/km ²)	Route density	2.4
平均线路长度	Avg. bus route length (km)	16.7
线路重复系数	Route overlap rate	7.2
线路非直线系数	Avg. non-linear coefficient	1.8
最大线路长度	Max. route length	33.9
最小线路长度	Min. route length	3.6

Scenario building

Combination \ Length	8-25km	6-20km	4-16km
	No rail route	S1	S2
Short-term (3 rail routes)	S4	S5	S6
Long-term (8 rail routes)	S7	S8	S9

Layers

- BusBRTRail
- BusRail
- BusRail_Stc
- BusRailRou
- BusRailRou
- BusRailRou
- RoadArc

NRBusf

- 1 - 2
- 3 - 5
- 6 - 9
- 10 - 15
- 18 - 30

- BusBRT
- Rail
- BRT



Bus+Short-term rail:
Cover **1284** road segments

- Bus Stop
- Bus termin
- BusRoute
- BusRouteE
- BusRouteC
- BusRouteC
- RoadArc

NrOfRc

- 1 - 2
- 3 - 5
- 6 - 10
- 11 - 18
- 19 - 38

- RoadNode
- RoadArc
- modpopwuha



Only bus:
Cover **1270** road segment

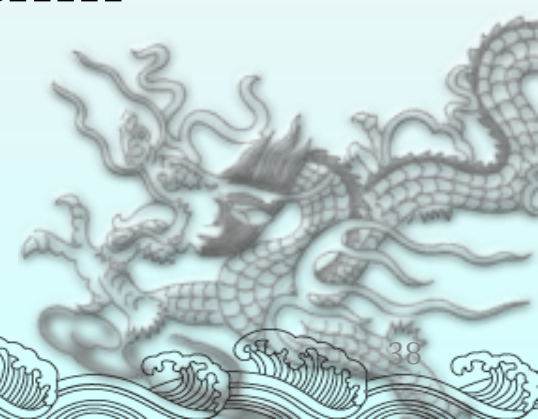
	No rail			Short-term rail			Long-term rail		
	S1	S2	S3	S4	S5	S6	S7	S8	S9
Available network size (nr. of routes)	512	493	384	346	335	253	299	281	150
Opt. network size (Nr. of routes)	280	280	280	280	280	253	280	280	150
Total bus route length (km)	4302	3559	2912	4323	3563	2919	4087	3477	2891
Avg. bus route length (km)	15.4	12.7	10.4	15.4	12.7	10.4	14.6	12.4	10.3
Route density	2.32	2.43	2.28	2.4	2.4	2.4	2.4	2.4	2.4
Avg. non-linear coefficient	1.41	1.41	1.48	1.45	1.45	1.49	1.46	1.46	1.51
Route overlap rate	6.8	5.3	4.6	6.6	5.4	4.4	6.2	5.3	4.4
300m population coverage (%)	62.5	63	61.4	63.2	63.7	62.7	64.6	62.8	62.6
500m population coverage(%)	87.6	87.9	84.5	87.9	87.4	86.2	88.2	86.6	87.2
Non-transfer accessibility (%)	15.1	13.3	11.5	20.8	20.2	16.4	17.0	16.9	16.7

Transit assignment: an evaluation of (6-12km)

Flows on base road segment (person/hr)	S2 (only bus)		S5 (short-term rail)		S8 (long-term rail)		Current	
	total seg. Length (km)	%	total seg. Length (km)	%	total seg. Length (km)	%	total seg. Length (km)	%
>1440	0	0	0.8	0.01	21.9	0.33	67.5	1.06
960-1440	29.7	0.21	197.7	2.07	830.5	12.7	600.6	9.46
480-960	2180.9	15.45	2681.1	28.10	2231.5	34.15	1012.4	15.95
240-480	3430.9	24.31	2356.2	24.69	1329.9	20.35	1252.4	19.73
120-240	2491.6	17.65	1621.7	16.99	872.6	13.35	1060.5	16.71
<120	5976.3	42.35	2683.6	28.12	1247.1	19.08	2351.9	37.06

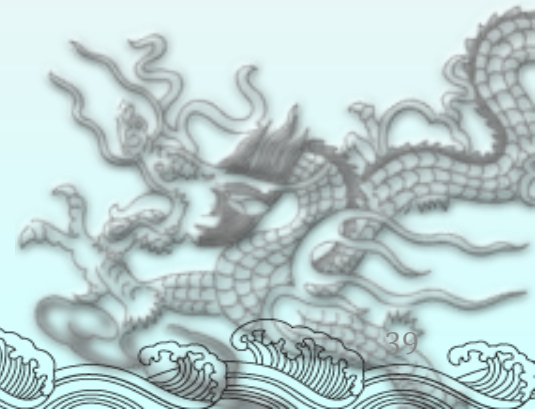
Conclusions

- ◆ A framework for bus network optimization during rail construction in large cities
- ◆ Generating preliminary bus route scenario
- ◆ Stop-based route creation
- ◆ Production and attraction at stops
- ◆ Optimization with genetic algorithm
- ◆ Indicator computing



Discussion

- ◆ Fitness function of GA (coverage vs flow-capacity ratio, or other indicators such as travel time)
- ◆ Transit assignment (to give more detailed information, e.g., flows, travel time)



Thanks!



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