Preferred citation style

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Predicting link speeds with floating car data

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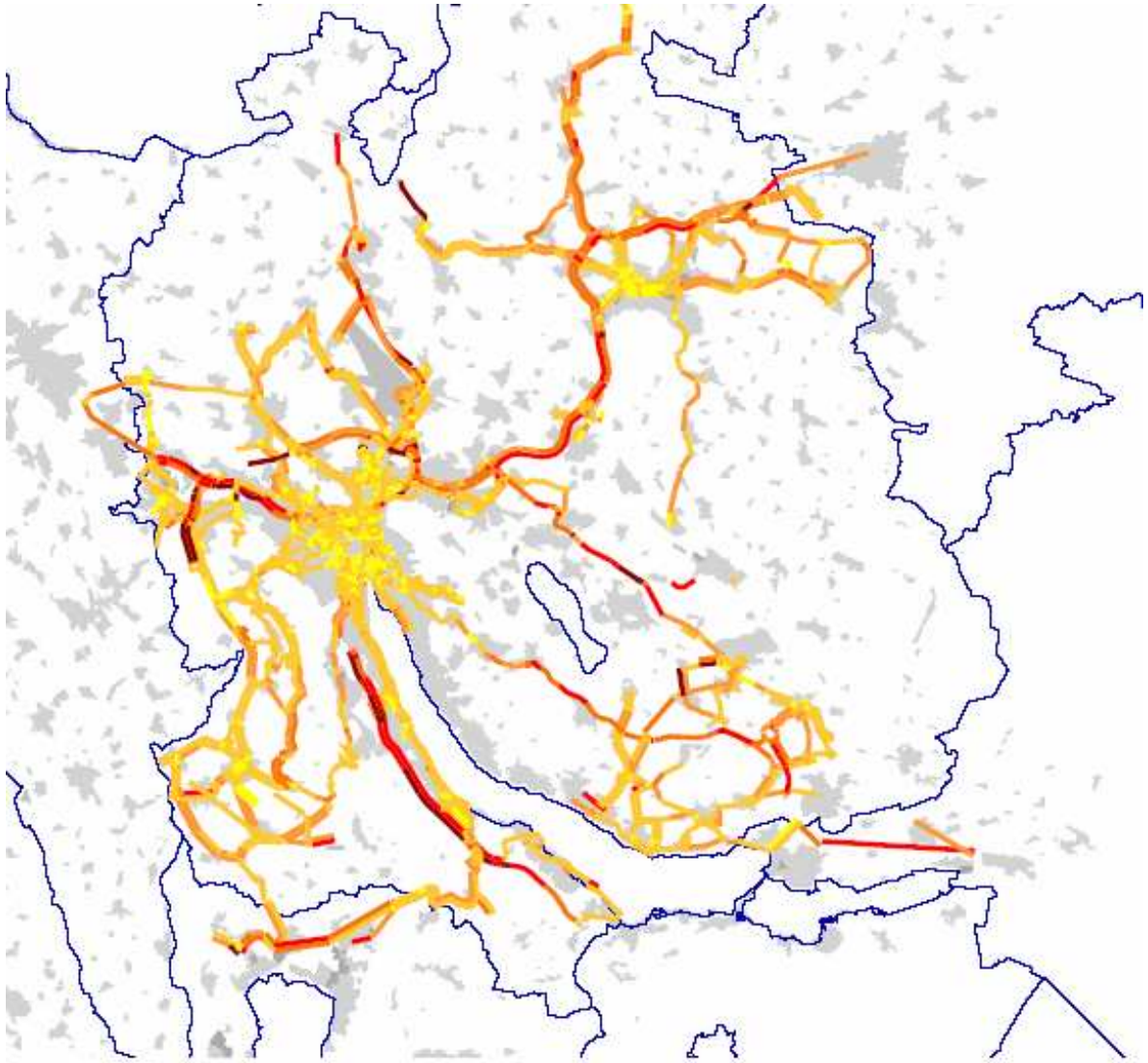
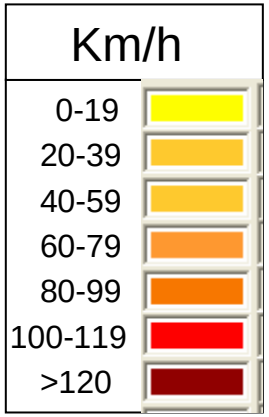
Average weekday peak hour speeds (Kanton Zürich)





Hackney and Bernard, 2005

Typical modelling aims

Predicting travel times (speeds):

- Shortest paths employing mean speeds by link type
- (Shortest paths employing comprehensive historical link data)
- (Dynamic) assignment results

Monitoring policy success:

- Local before-and-after measurements
- Congestion indices

Alternative approach and its model formulation

Speed = Y =

$\rho W_a Y$ +		(spatial autoregressive)
Time of day dummy		+
Link type dummy		+
Population density	* link type dummy	+
Employment density	* link type dummy	+
Network density	* link type dummy	+
Motorway access density	* link type dummy	+
$\lambda W_e \varepsilon$ +		(spatially lagged errors)
u		~ N(0,σ)

W: Matrix of spatial weights

Alternative approach and its model formulation

	$\rho W_a Y$	$\lambda W_e \varepsilon$	$u \sim N(0,\sigma)$
OLS			✔
Spatial error model (SEM)		✔	✔
Spatial autoregressive model (SAR)	✔		✔
General spatial model (SAC)	✔	✔	✔

Plus/Minus

Benefits:

- Usage of existing data
- Seperating the effects of network improvements from employment and population effects (Monitoring)
- Quicker turn around then network modelling

Distadvantages:

- Parametric assumptions
- Averaging over locations
- Uniformity of weighting

Dataset

Collected with three vehicles during November 2003

3 circuits (550-700km length) of 50 stages (11-14km) each

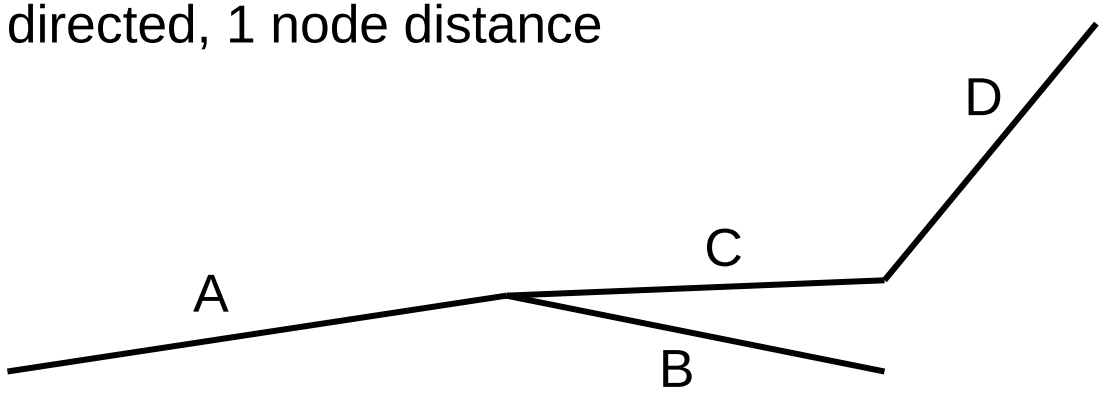
2.5 Mio. seconds observed including invalid observations
2.0 Mio. valid seconds

Aggregated to 52,000 observations for 3,680 directional links
50% of the links are measured at least 11 times (average: 13)

Sponsor: Kanton Zürich

Spatial weighting matrix W (1) – Example of assembly

Contiguity: directed, 1 node distance



Contiguity matrix:

sum(rows)=1

W	A	B	C	D
A	0	0.5	0.5	0
B	0.5	0	0.5	0
C	0.33	0.33	0	0.33
D	0	0	1	0

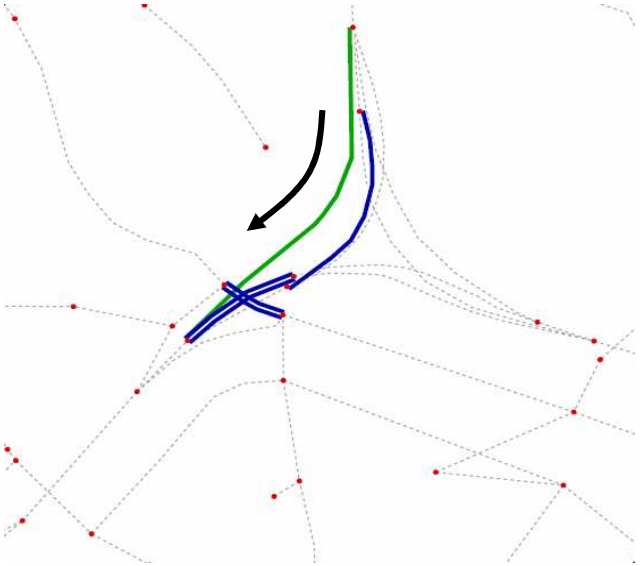
Spatial weighting matrix (2) – Spatial/network neighbour

Spatial neighbour:

- n closest links from centre of link

5 spatial neighbours

(Euclidian distance)

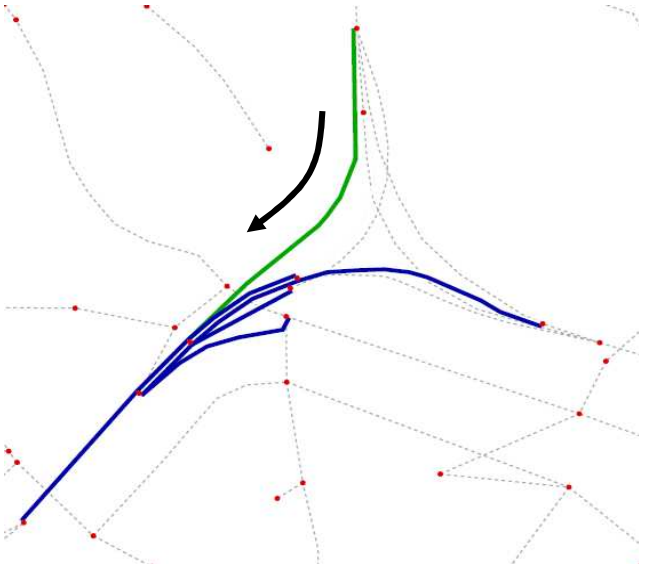


Network neighbour:

- reachable links passing n (max.) intersections

2 intersections → ~5 neighbours

(network distance)



Best spatial weighting

Model	Best W-matrix	$\overline{R}^2$
Weighted least squares (WLS)	*not needed*	0.5347
Spatial error model (SEM)	W_a: *not needed* W_e: 3 network neighbours	0.5749
Spatial autoregressive model (SAR)	W_a: 4 network neighbours W_e: *not needed*	0.5518
General spatial model (SAC)	W_a: 4 network neighbours W_e: 3 network neighbours	0.5827

Differences in conclusions

Variable		SAC Estimates	Difference to WLS
Motorways*	highway access r=1km	-1.81	0.58
Motorways*	ln(empl. opp. r=5km)	-4.43	0.02
Trunk roads*	ln(empl. opp. r=1km)	-5.59	1.75
Trunk roads*	ln(population r=5km)	-3.13	1.53
Collector roads*	ln(empl. opp. r=1km)	-2.86	0.00
Collector roads*	ln(population r=3km)	-4.07	1.47
Distributor roads*	ln(empl. opp. r=1km)	-4.27	1.05
Distributor roads*	ln(population r=5km)	-0.64	5.01
Other roads*	ln(empl. opp. r=1km)	1.20	5.82
Density highways [m/ha]		0.02	-3.39
Density trunk roads [m/ha]		0.00	-0.63
Density distributor roads [m/km]		0.00	-1.31
Density urban collector roads [m/km]		0.00	0.57
Density urban distributor roads [m/km]		0.00	0.80
Dummies for link type * time-of-day means			
ρ		0.39	
λ		0.19	

Appendices

Literature and references

Marchal, F., J.K. Hackney and K.W. Axhausen (2005) Efficient map-matching of large GPS data sets - Test on a speed monitoring experiment in Zurich, Conference Paper, STRC, Monte Verità.

Hackney, J., F. Marchal and K.W. Axhausen (2004) Monitoring a road system's level of service: The Canton Zurich floating car study 2003, paper presented at the 84th Annual Meeting of the Transportation Research Board, Washington, D.C., January 2005.

Hackney, J. and M. Bernard (2005) A spatial regression model of traffic speed in Zurich, IVT Seminar, ETH, December 2005.

Overview: Applied models (1)

Ordinary Least Sqares model (OLS, WLS):

$$y = \beta X + \varepsilon \qquad \varepsilon \sim N(0, \sigma)$$

Spatial Error Model (SEM):

$$y = \beta X + u$$

$$u = \lambda W_e u + \varepsilon \quad \varepsilon \sim N(0, \sigma)$$

with W: contiguity matrix

Overview: Applied models (2)

Spatial Autoregressiv Model (SAR):

$$y = \rho W y + \beta X + \varepsilon \qquad \varepsilon \sim N(0, \sigma)$$

General Spatial Model (SAC):

$$y = \rho W_a y + \beta X + u$$
$$u = \lambda W_e u + \varepsilon \quad \varepsilon \sim N(0, \sigma)$$

with W: contiguity matrix

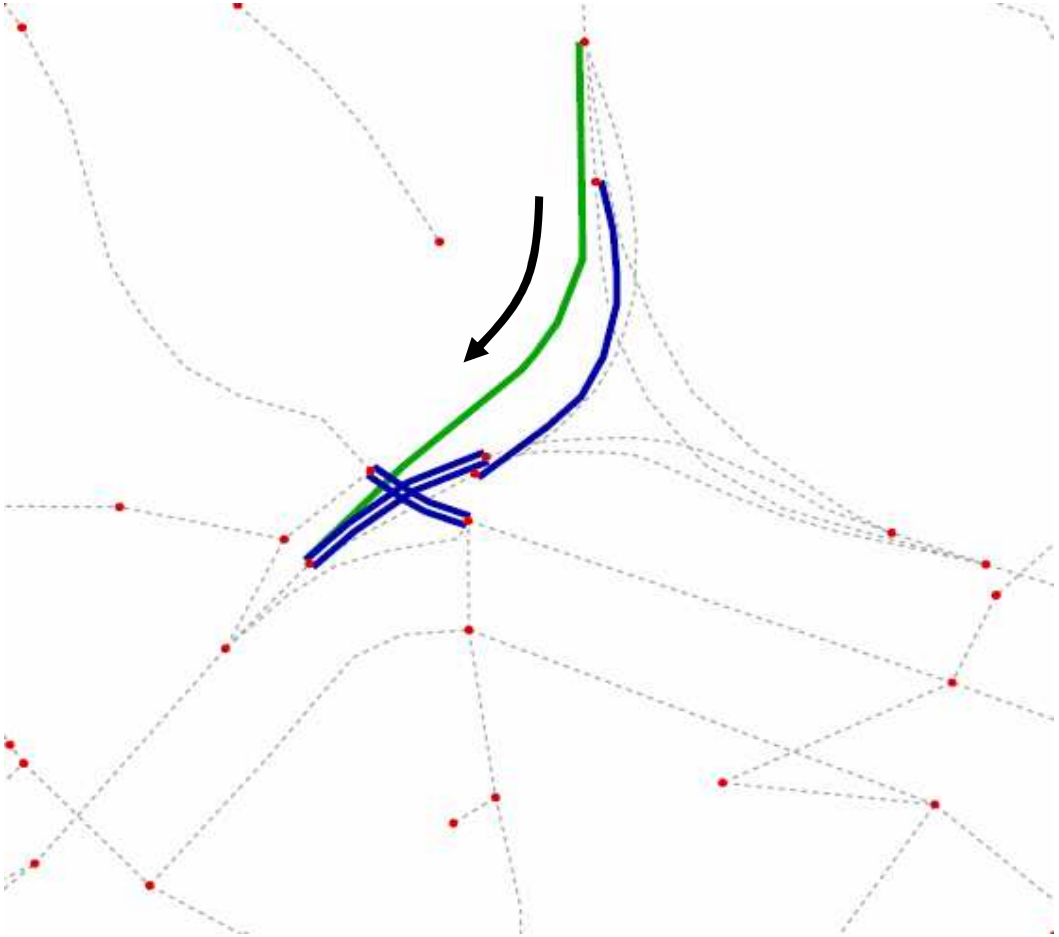
Spatial weighting matrix W (2) – Spatial neighbour

Spatial neighbour:

- n closest links from centre of link

5 spatial neighbours

(Euclidian distance)



Spatial weighting matrix W (3) – Network neighbour

Spatial neighbour:

- n closest links from centre of link

5 spatial neighbours

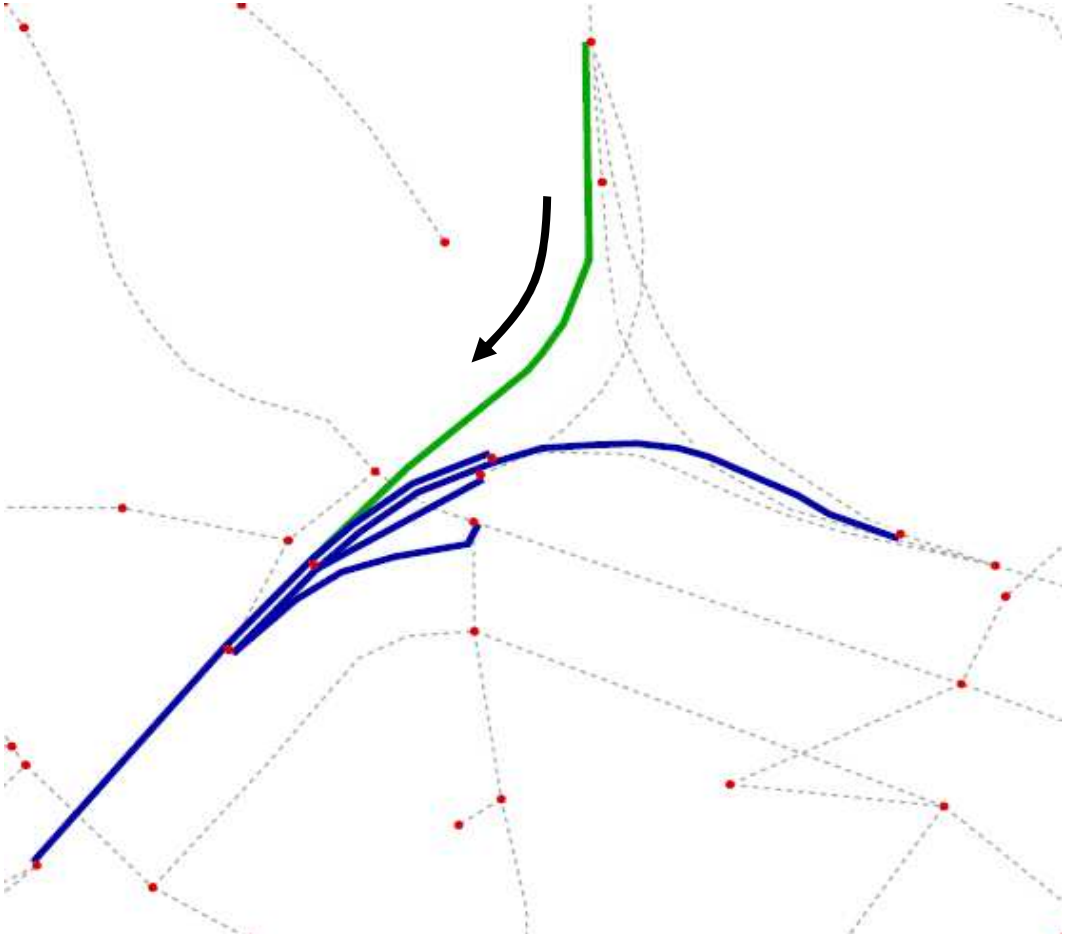
(Euclidian distance)

Network neighbour:

- reachable links passing n (max.) intersections

2 intersections → ~5 neighbours

(network distance)



Categories

Time of Day:

Peak:	Morning- (0630-0830) and Evening Peaks (1630-1830)
Off peak:	Day (0830-1630) and (1830-2030)
Shoulder:	Night and early morning (2030-2100; 0600-0630)

Type of Day:

Workday/Weekend (Saturday) all hours

Road type:

Code	Name	Nr.
Highway	“Hochleistungsstrassen” (High Speed Network)	10
Trunk road	“Hauptstrassen/Verbindungsstrassen” (Main Trunk Roads)	20
Collector rd.	“Sammelstrassen” (Collectors)	30
Distributor rd.	“Erschliessungsstrassen” (Distributor Roads)	40

Average system speeds

Road type	Data	Saturday	HVZ (Peak)	NVZ (Off-peak)	RVZ (Other)	Mo.-Fr.	Total
HLS (motorway and similar)	Average	101.2	85.3	101.5	93.0	96.1	97.1
	Standard Deviation	8.3	5.5	8.3	7.0	6.8	8.1
	Number of Observations	2495	2235	6306	991	9532	12027
	Km driven	1475.9	1359.4	3703.2	628.4	5691.0	7166.9
HVS/HVSII (trunk roads)	Average	40.5	35.0	39.0	41.6	38.1	38.6
	Standard Deviation	2.1	1.5	1.9	2.8	1.8	2.1
	Number of Observations	5696	5246	14732	2648	22626	28322
	Km driven	2159.5	2244.9	5808.1	846.8	8899.7	11059.2
SS (collector)	Average	50.9	41.7	46.1	48.3	45.0	46.1
	Standard Deviation	3.0	2.2	2.1	4.7	1.9	1.8
	Number of Observations	1118	1195	3052	258	4505	5623
	Km driven	753.0	728.1	2057.0	185.5	2970.6	3723.5

Calculation of Average Speed per Link

The matched GPS points give entry and exit times for each link

$$\bar{t} = t_{exit} - t_{enter}$$

The speed is the length of the link divided by the time to drive across it.

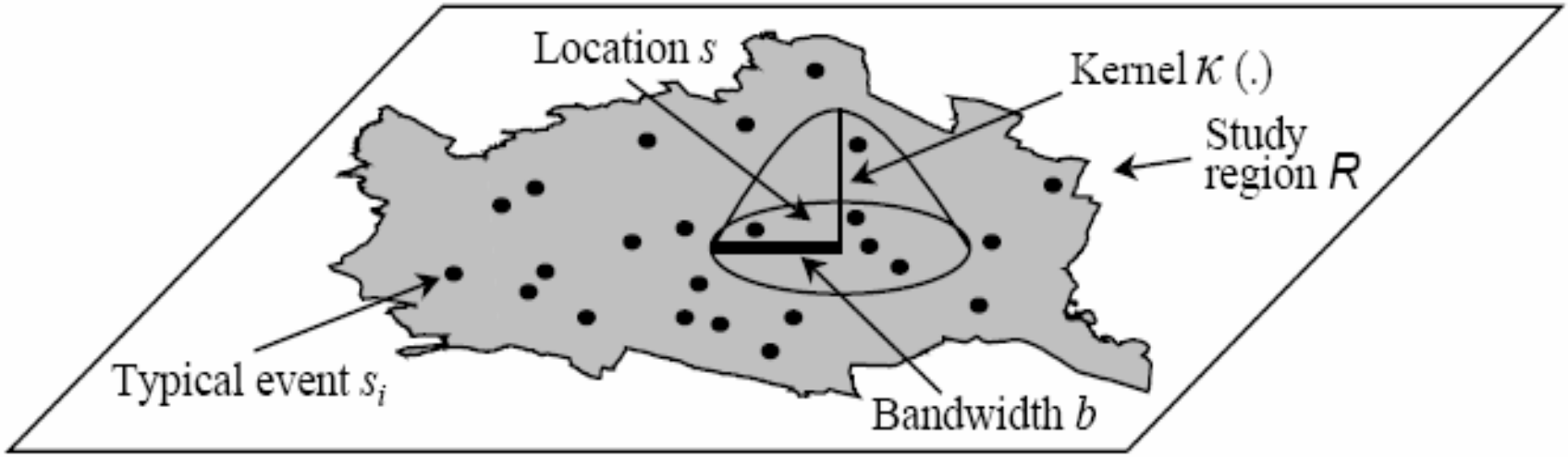
Space Mean Speed for N measurements is

$$\overline{V} = \frac{(x_1 + x_2 + x_3 + \Lambda + x_n)}{(t_1 + t_2 + t_3 + \Lambda + t_n)}$$

where x is link length and n is the observation (trip across the link)

Kernel Density Averaging of Hectare Data

Radii of influence of 1km, 3km, 5km



Bailey and Gatrell (1995)

Estimates WLS – SEM (1)

Variable		WLS		SEM	
		Coeff.	t-Prob.	Coeff.	z-Prob.
Highways*	Saturday	127.14	0.000	145.74	0.000
Highways*	Peak hours	116.37	0.000	134.87	0.000
Highways*	shoulder	125.37	0.000	143.24	0.000
Highways*	off peak hours	128.37	0.000	145.99	0.000
Trunk roads*	Saturday	119.71	0.000	119.82	0.000
Trunk roads*	Peak hours	113.89	0.000	114.25	0.000
Trunk roads*	shoulder	116.12	0.000	116.25	0.000
Trunk roads*	off peak hours	119.65	0.000	119.93	0.000
Collector roads*	Saturday	106.83	0.000	106.12	0.000
Collector roads*	Peak hours	100.50	0.000	101.10	0.000
Collector roads*	shoulder	103.52	0.000	102.60	0.000
Collector roads*	off peak hours	102.30	0.000	104.06	0.000
Distributor roads*	Saturday	111.01	0.000	105.99	0.000
Distributor roads*	Peak hours	106.05	0.000	101.42	0.000
Distributor roads*	shoulder	107.43	0.000	103.43	0.000
Distributor roads*	off peak hours	111.33	0.000	105.59	0.000
Other roads*	Saturday	62.96	0.000	63.17	0.000
Other roads*	Peak hours	60.26	0.000	60.23	0.000
Other roads*	peak shoulder	62.53	0.000	60.93	0.000
Other roads*	off peak hours	63.03	0.000	65.23	0.000

Estimates WLS – SEM (2)

Variable		WLS		SEM	
		Coeff.	t-Prob.	Coeff.	z-Prob.
Highways*	highway access r=1km	-2.39	0.000	-1.38	0.001
Highways*	ln(empl. opp. r=5km)	-4.46	0.004	-10.44	0.000
Trunk roads*	ln(empl. opp. r=1km)	-7.34	0.000	-6.76	0.000
Trunk roads*	ln(population r=5km)	-4.66	0.000	-5.07	0.000
Collector roads*	ln(empl. opp. r=1km)	-2.86	0.006	-3.56	0.001
Collector roads*	ln(population r=3km)	-5.53	0.000	-4.94	0.001
Distributor roads*	ln(empl. opp. r=1km)	-5.32	0.000	-5.38	0.000
Distributor roads*	ln(population r=5km)	-5.65	0.001	-4.67	0.014
Other roads*	ln(empl. opp. r=1km)	-4.63	0.075	-3.82	0.140
Density highways [m/ha]		3.40	0.000	0.02	0.000
Density trunk roads [m/ha]		0.64	0.004	0.01	0.020
Density distributor roads [m/ha]		1.31	0.001	0.01	0.117
Density urban collector roads [m/ha]		-0.57	0.007	0.00	0.954
Density urban distributor roads [m/ha]		-0.81	0.000	0.00	0.063
Rho		-		-	-
Lambda		-		0.48	0.000
$\overline{R}^2$		0.5347		0.5749	

Estimates WLS – SAC (1)

Variable		WLS Sign	WLS t-Prob.	SAC Sign	SAC z-Prob.
Highways*	Saturday	+	0.000	+	0.000
Highways*	Peak hours	+	0.000	+	0.000
Highways*	shoulder	+	0.000	+	0.000
Highways*	off peak hours	+	0.000	+	0.000
Trunk roads*	Saturday	+	0.000	+	0.000
Trunk roads*	Peak hours	+	0.000	+	0.000
Trunk roads*	shoulder	+	0.000	+	0.000
Trunk roads*	off peak hours	+	0.000	+	0.000
Collector roads*	Saturday	+	0.000	+	0.000
Collector roads*	Peak hours	+	0.000	+	0.000
Collector roads*	shoulder	+	0.000	+	0.000
Collector roads*	off peak hours	+	0.000	+	0.000
Distributor roads*	Saturday	+	0.000	+	0.026
Distributor roads*	Peak hours	+	0.000	+	0.023
Distributor roads*	shoulder	+	0.000	+	0.020
Distributor roads*	off peak hours	+	0.000	+	0.029
Other roads*	Saturday	+	0.000	-	0.625
Other roads*	Peak hours	+	0.000	-	0.715
Other roads*	peak shoulder	+	0.000	-	0.714
Other roads*	off peak hours	+	0.000	-	0.702

Estimates WLS – SAC (2)

Variable		WLS Sign	WLS t-Prob.	SAC Sign	SAC z-Prob.
Highways*	highway access r=1km	-	0.000	-	0.000
Highways*	ln(empl. opp. r=5km)	-	0.004	-	0.006
Trunk roads*	ln(empl. opp. r=1km)	-	0.000	-	0.000
Trunk roads*	ln(population r=5km)	-	0.000	-	0.000
Collector roads*	ln(empl. opp. r=1km)	-	0.006	-	0.004
Collector roads*	ln(population r=3km)	-	0.000	-	0.003
Distributor roads*	ln(empl. opp. r=1km)	-	0.000	-	0.001
Distributor roads*	ln(population r=5km)	-	0.001	-	0.761
Other roads*	ln(empl. opp. r=1km)	-	0.075	+	0.674
Density highways [m/ha]		+	0.000	+	0.001
Density trunk roads [m/ha]		+	0.004	+	0.070
Density distributor roads [m/km]		+	0.001	+	0.820
Density urban collector roads [m/km]		-	0.007	+	0.775
Density urban distributor roads [m/km]		-	0.000	+	0.017
ρ				+0.39	0.000
λ				+0.19	0.000
$\overline{R}^2$		0.5347		0.5827	

Differences in conclusions (1)

Variable		SAC Estimates	Difference to WLS
Highways*	Saturday	88.70	-38.44
Highways*	Peak hours	81.64	-34.74
Highways*	shoulder	88.07	-37.29
Highways*	off peak hours	88.13	-40.25
Trunk roads*	Saturday	82.66	-37.04
Trunk roads*	Peak hours	78.93	-34.96
Trunk roads*	shoulder	80.58	-35.54
Trunk roads*	off peak hours	82.38	-37.27
Collector roads*	Saturday	66.92	-39.91
Collector roads*	Peak hours	64.80	-35.70
Collector roads*	shoulder	65.83	-37.70
Collector roads*	off peak hours	64.00	-38.30
Distributor roads*	Saturday	43.43	-67.58
Distributor roads*	Peak hours	42.49	-63.56
Distributor roads*	shoulder	43.63	-63.80
Distributor roads*	off peak hours	43.08	-68.26
Other roads*	Saturday	-10.82	-73.78
Other roads*	Peak hours	-7.64	-67.90
Other roads*	peak shoulder	-7.75	-70.29
Other roads*	off peak hours	-8.62	-71.65

Differences in conclusions (2)

Variable		SAC Estimates	Difference to WLS
Highways*	highway access r=1km	-1.81	0.58
Highways*	ln(empl. opp. r=5km)	-4.43	0.02
Trunk roads*	ln(empl. opp. r=1km)	-5.59	1.75
Trunk roads*	ln(population r=5km)	-3.13	1.53
Collector roads*	ln(empl. opp. r=1km)	-2.86	0.00
Collector roads*	ln(population r=3km)	-4.07	1.47
Distributor roads*	ln(empl. opp. r=1km)	-4.27	1.05
Distributor roads*	ln(population r=5km)	-0.64	5.01
Other roads*	ln(empl. opp. r=1km)	1.20	5.82
Density highways [m/ha]		0.02	-3.39
Density trunk roads [m/ha]		0.00	-0.63
Density distributor roads [m/km]		0.00	-1.31
Density urban collector roads [m/km]		0.00	0.57
Density urban distributor roads [m/km]		0.00	0.80
ρ		0.39	
λ		0.19	
$\overline{R}^2$		0.5827	