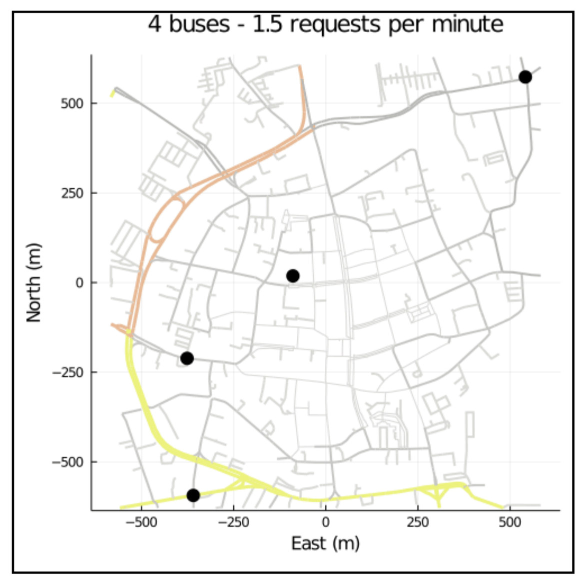
request id	bus id	direct time (minutes)	submit time (minutes)	pickup time (minutes)	dropoff time (minutes)	extra time (direct times)
86	3	1.4	52.4	54.6	56.1	1.57
87	2	3.1	52.7	53.9	58.4	0.82
88	1	1.2	52.9	53.2	56.9	2.37
89	3	1.0	55.2	57.4	58.4	2.17
90	1	1.5	55.6	55.9	58.7	1.07
91	2	1.7	57.6	58.4	60.1	0.48
92	5	1.6	57.8	58.0	61.1	1.02
93	4	2.1	57.9	58.9	62.9	1.34
94	3	2.1	59.2	60.7	63.7	1.17
95	1	1.5	59.3	62.1	63.9	2.1
96	1	2.6	59.4	60.9	on bus 1	
97	5	1.1	59.4	60.0	62.0	1.27
98	3	1.6	60.5	60.7	62.3	0.1
99	4	0.4	60.6	61.1	61.6	1.24
100	2	2.3	61.5	64.1	on bus 2	
101	5	0.9	62.3	62.3	63.2	0.0
102	1	1.0	62.5	63.7	on bus 1	
103	4	0.8	63.4	64.0	on bus 4	
104	5	3.1	63.7	64.6	on bus 5	
105	3	1.1	64.0	waiting for bus 3		
106	0	1.8	65.2			

bus id	passengers	to do list
1	[96, 102]	-96; -102;
2	[100]	-100;
3		105; -105;
4	[103]	-103;
5	[104]	-104;



Ride-pooling dynamics

silent assumptions:
- request-times Poissonian
- zero stop time

Setup (given)

$\mathcal{M}$: map
N : #buses
Γ : spatial request distribution
f : request frequency $[s^{-1}]$
$\mathcal{D} = (\mathcal{C}, \mathcal{P})$: dispatcher algorithm
$\mathcal{C}$: cost function
$\mathcal{P}$: rejection policy, i.e. $(\delta_{\max}^{\text{total}},\ t_{\max}^{w})$

Simulations: MatSim, Julia, Pyd3t

collected data

each request i :
(d, t) : direct distance/time
(D, T) : actual distance/time on bus
T^w : waiting time
χ : indicator; served=1, rejected=0

each bus k :
$\{(\sigma_j, \tau_j)\}_{j \in \text{jobs}}$: job distance/duration

direct observables:

$p_{\text{served}} = \langle \chi \rangle$: served percentage
$p_{\text{busy}} = \dfrac{\sum_{k,j} \tau_{k,j}}{N \cdot t_{\text{sim}}}$: bus utilization
$v \in \{ \dfrac{\langle d \rangle}{\langle t \rangle}, \langle \dfrac{d}{t} \rangle, \dfrac{\langle \sigma \rangle}{\langle \tau \rangle}, \langle \dfrac{\sigma}{\tau} \rangle \}$: mean velocity
$\langle \delta \rangle \in \{ \dfrac{\langle D \rangle}{\langle d \rangle}, \langle \dfrac{D}{d} \rangle, \dfrac{\langle T \rangle}{\langle t \rangle}, \langle \dfrac{T}{t} \rangle \}$: mean detour
$\langle b \rangle \in \{ \dfrac{\sum_i D_i}{\sum_{k,j} \sigma_{k,j}}, \dfrac{\sum_i T_i}{\sum_{k,j} \tau_{k,j}} \}$: mean occupancy
$\langle b \rangle^* \in \{ \dfrac{\sum_i D_i}{\sum_{\text{non-empty}} \sigma_{k,j}}, \dfrac{\sum_i T_i}{\sum_{\text{non-empty}_{k,j}} \tau_{k,j}} \}$: non-zero occupancy

Experiment: Harz, Leipzig, Kassel

Michael's taxi data

Ecobus

Observables

$\langle \delta \rangle$: mean detour
$\langle b \rangle$: mean occupancy
$\langle T^w \rangle$: mean waiting time
p_{served} : served percentage

Targets

$\eta = \dfrac{\langle \delta \rangle}{\langle b \rangle}$: efficiency
$Q = \dfrac{\langle t \rangle}{\delta\ \langle t \rangle + \langle T^w \rangle}$: quality

Theory

supply-demand

$v N \langle b \rangle \cdot p_{\text{busy}} = \langle \delta \rangle \langle d \rangle f \cdot p_{\text{served}}$

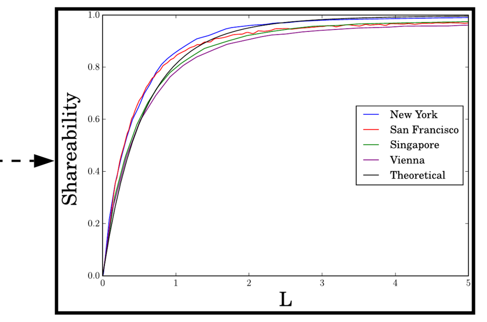
insufficient: 1 equation, 4 variables

need model(s)

Strogatz shareability

obtain L from setup: $L = \dfrac{f\ (v\Delta)^3}{v\ |\Omega|}$

shareability $S(L) = 1 - p(k = 0)$



$$\mathcal{NS}_f(t_A) = \int_\Omega \int_\Omega d\mathbf{x}_A d\mathbf{y}_A \rho(\mathbf{x}_A, \mathbf{y}_A) \sum_{N \geq 0} e^{-\Lambda} \frac{\Lambda^N}{N!} \left(1 - p(\mathbf{x}_A, \mathbf{y}_A, t_A)\right)^N$$

$p(k)$

N required?

$p(B \sim C | A \sim B \wedge A \sim C)$ → $p(b^*)$

$\langle b^* \rangle$

modified ellipse model

$\#\text{extra-stops} = 2\ (\langle b \rangle^* - 1)$

$\delta_{\max}^{\text{total}}$ → $\langle \delta \rangle\ (b^*, \delta_{\max}^{\text{total}})$

wormlike chain persistence length

$\langle d \rangle$

minimum of N iid random variables

$N \to \infty$

Mean-field theory

assume $\langle b \rangle^*$ given
assume $p_{\text{served}} = p_{\text{busy}} = 1$
introduce $\delta_{\max}$ as $\mathcal{P}$ for each stop
specify $\mathcal{M} = \mathcal{R}^2$

$\#\text{extra-stops} = 2\ (\langle b \rangle^* - 1)$

Poissonian bus distribution with general area λ

ellipse model → ribbon picture → waiting time

$\langle \delta \rangle\ (b^*, \delta_{\max})$

supply-demand with $p_{\text{busy}} = p_{\text{served}} = 1$ → $\langle b \rangle\ (\langle \delta \rangle)$

waiting time models

David: volume growth on a graph

waiting time models: closest point in sphere

waiting time

Helge: Queue dynamics