A Recursive Logit Route Choice Model Considering Link Perceptions with An Application to Tokyo

Tokyo Tech & ETH Zurich
Noriko KANEKO

CONTENTS

1.BACKGROUND

- The construction of three ring roads
- Seamless tolls in highway with new toll collection
- Dynamic traffic information provided by ETC2.0

→The possibility of drastic change of traffic flow pattern

The necessity to conduct detailed route choice model to evaluate traffic policy

1.BACKGROUND

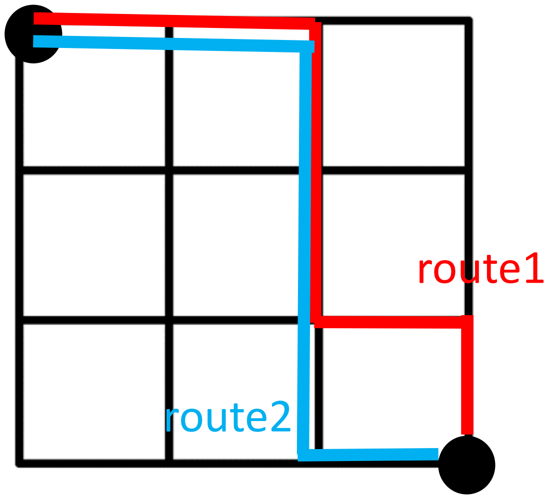
Route Choice Model

The path-based model is typically used, but

①The difficulty to enumerate path alternatives

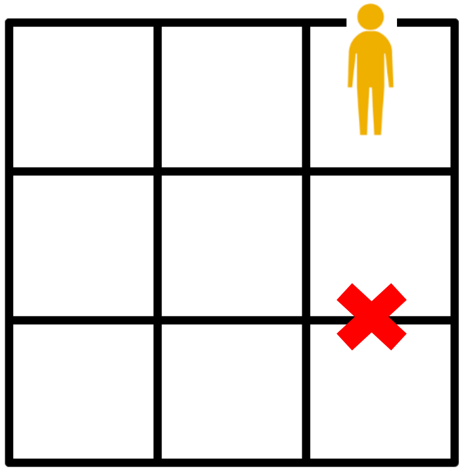
②The validity of assumption that traveler determine all of path at the origin

①



$$ {}_{6}C_{3} = 20 $$

②



1.BACKGROUND

Route Choice Model

The path-based model is usually used

①The difficulty to enumerate path alternatives

②The validity of assumption that traveler determine all of path at the origin

Conventional Path-based model has limitations!

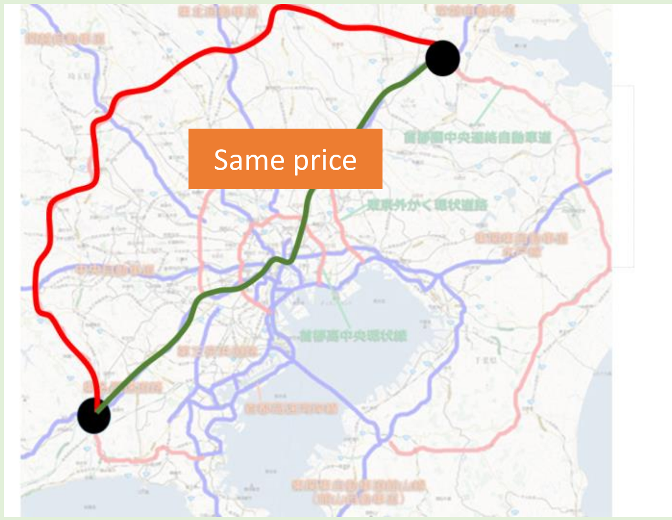
Link-based Recursive Logit Model **Fosgerau et al. (2013)**

the model thinks that traveler choose next link at each node recursively

1.BACKGROUND

	Path Based Model	Link Based Model
Advan tage	• All of the attribute can be contained in	• Needless to enumerate path alternatives
Dis-Advan tage	• The difficulty to enumerate path alternatives • The validity of assumption that traveler determine all of path at the origin	• the difficulty to contain non link-additive attribute(Ex Price) • The heavy computation load

1.BACKGROUND



The toll in highway depends on only origin and destination (non link-additive)

Advantage		
Dis-Advantage	• The difficulty to enumerate path alternatives • The validity of assumption that traveler determine all of path at the origin	• the difficulty to contain non link-additive attribute(Ex Price) • The heavy computation load

1.BACKGROUND

Link number

Link number

$$\begin{pmatrix} a_{11} & \cdots & a_{1n} \\ a_{12} & & a_{2n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{pmatrix}$$

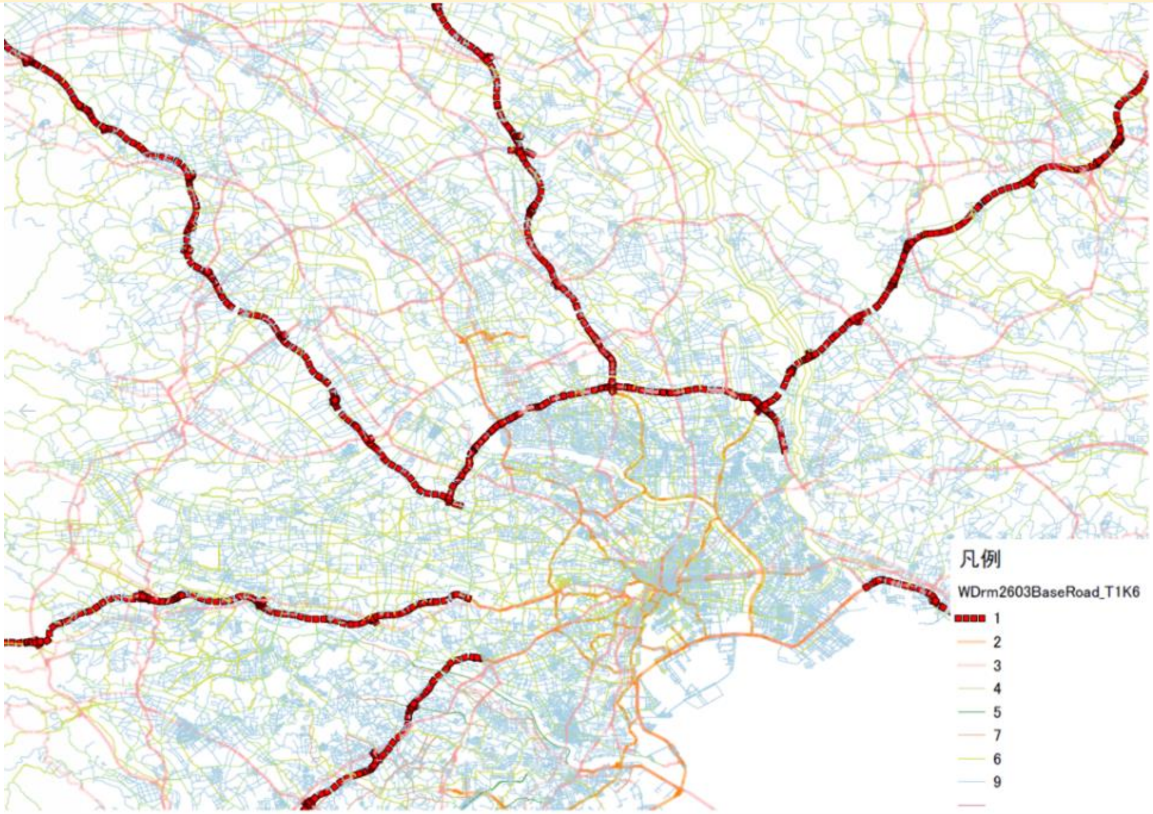
The necessity to calculate huge inverse matrix
(It must be satisfied Hawkins-Simon's condition)

(Ex.)200000 × 200000
(Tokyo Metropolitan Area)

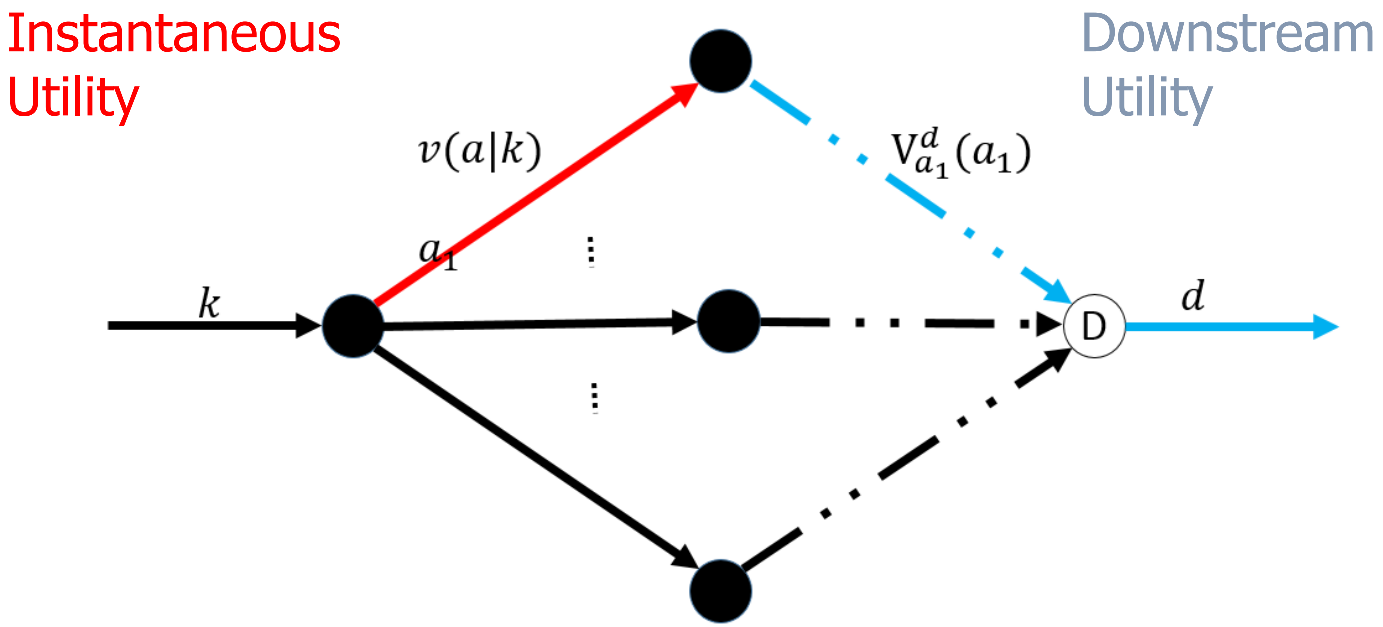
Advantage		
Dis-Advantage	• The difficulty to enumerate path alternatives • The validity of assumption that traveler determine all of path at the origin	• the difficulty to contain non link additive attribute(Ex Price) • The heavy computation load

2.PURPOSE

Developing a recursive logit (RL) type route choice model in Tokyo Metropolitan Area. Introducing a link perception structure by which computational challenges in RL models would be relaxed.



3.METHODOLOGY



$G = (A, v)$: *network* v: *the set of node* A: *the set of link* $(k, a \in A)$
k: *state link* a: *potential action link at k* $A(k)$: *the link outgoing from k*
d: *dummy link from destination* $\tilde{A}$: *the set of all link* $\tilde{A} = A \cup d$

- The basic concept of RL

  A traveler n choose the next link that maximize the sum of instantaneous utility $v(a|k)$ and Downstream utility $V_{a_1}^d(a_1)$

3. METHODOLOGY

- The basic concept of RL

A traveler n choose the next link that maximize the sum of Instantaneous utility$v(a|k)$ and Downstream utility$V_{a_1}^{d}(a_1)$

- Instantaneous utility $v(a|k)$

the sum of deterministic utility and stochastic utility

$$u_n(a|k) = v_n(a|k) + \tau\varepsilon_n(a) \quad (\tau\text{: scale parameter})$$

(ex)

$$v(a|k) = \beta_{time}Time_a + \beta_{cost}Cost_a + \beta_{turn}UturnDummy$$

- Downstream utility $V_{a_1}^{d}(a_1)$

expected utility to the destination when traveler choose link a

$$V_n^d = E[\max(v_n(a|k) + \mu\varepsilon_n(a) + V_n^d(a)\ ]$$

- Link choice probability

i.i.d.extreme value type I error terms

$$P_n^d(a|k) = \frac{\exp\{v_n(a|k) + V_n^d(a)\ \}}{\sum \exp\{v_n(a|k) + V_n^d(a)\ \}}$$

The same shape as Multinominal Logit Model

3.METHODOLOGY

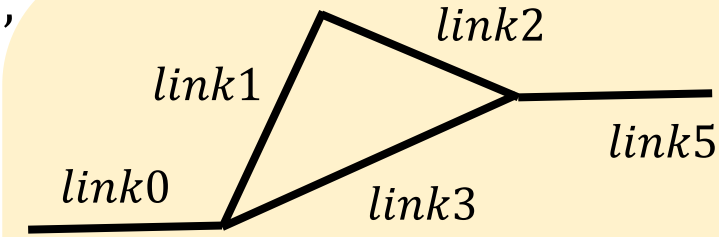
- To find the value of downstream utility $V^d(a)$,

$$V_n^d = \begin{cases} \mu \ln \sum \delta(a|k) \exp \frac{1}{\mu} \{ v_n(a|k) + V_n^d(a) \} \\ 0 \end{cases}$$

$$\Leftrightarrow M_{ka} = \begin{cases} \delta(a|k) \exp\left(\frac{1}{\mu} v_n(a|k) + V_n^d(a) \right) \\ 0 \end{cases}$$

$$\Leftrightarrow \boldsymbol{z} = \boldsymbol{M}\boldsymbol{z} + \boldsymbol{b}$$ Bellman equation

$$\Leftrightarrow \boldsymbol{z} = (\boldsymbol{I} - \boldsymbol{M})^{-1}\boldsymbol{b}$$



$$M = \begin{pmatrix} 0 & e^{01} & 0 & e^{03} & 0 \\ 0 & 0 & e^{12} & 0 & 0 \\ 0 & e^{32} & 0 & 0 & e^{0} \\ 0 & 0 & 0 & 0 & e^{0} \\ 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

$I \ : (|\tilde{A}| \times |\tilde{A}|)$ *the unit matrix*

$M : (|\tilde{A}| \times |\tilde{A}|)$ *the incidence matrix defining instantaneous utilities*

$z \ : (|\tilde{A}| \times \ 1)$ *a vector with* $z_k = \exp(1/\mu) V(k)$

$b \ : (|\tilde{A}| \times \ 1)$ *a vector with* $b_k = 0 (k \neq d), b_k = 1 (k = d)$

3. METHODOLOGY

By the Markov property , path choice probability is

$$P(\sigma) = \prod_{i=0}^{I-1} P(k_{i+1}|k_i)$$

Rearranging this formula,

$$(\sigma^n) = \frac{\exp(v(\sigma^n/\mu))}{\sum_{v(\sigma^{n'})\in\Omega}\exp(v(\sigma^{n'}/\mu))}$$

This is the equivalent of MNL with infinite path alternatives!!

Maximum problem of log likelihood is written as bellow

$$\max LL_n(\boldsymbol{\beta}) = \frac{1}{N}\sum_{n=1}^{N}\ln P(\sigma_n:\boldsymbol{\beta}) = \frac{1}{\mu}\sum_{n=1}^{N}\left\{\left[\sum_{i=0}^{I^n-1} v(k_{i+1}^n|k_i^n)\right] - V(k_0^n)\right\}$$

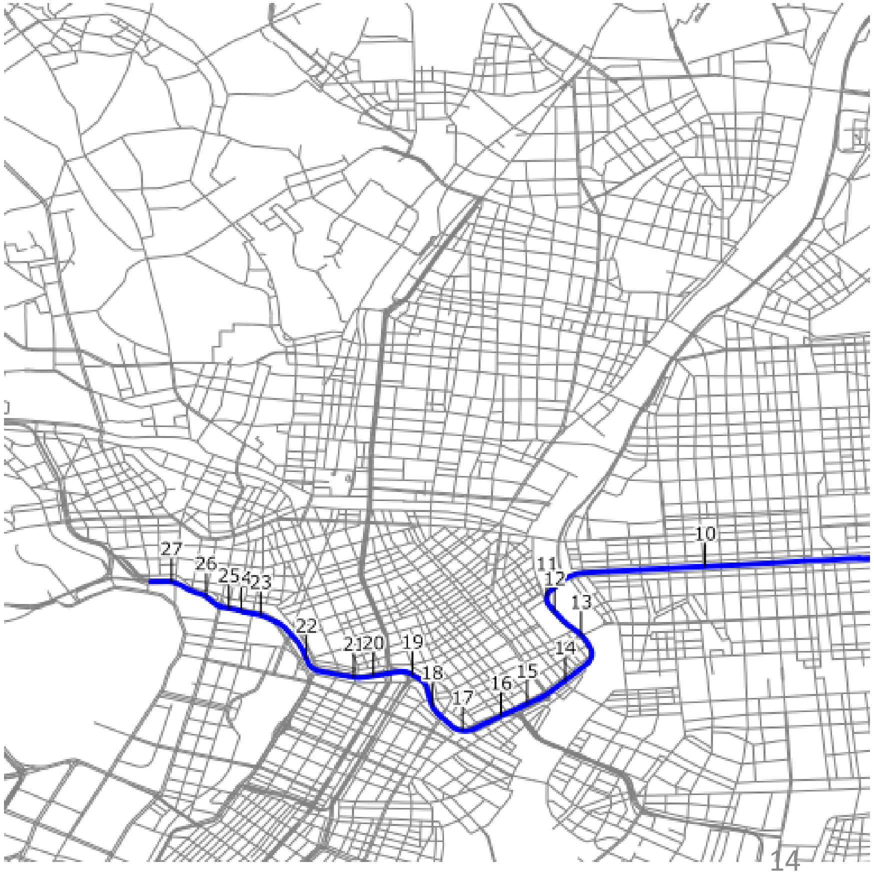
The formula is complicated!

The issue of Recursive logit model is the difficulty of calculations such an bellman equation, Log likelihood

3.DIFFICULTY

1. A huge inverse matrix (Link num × Link num) must be calculated
2. An appearance of cyclic route

$$M = \begin{pmatrix} 0 & e^{-v(1|0)} & \cdots & 0 \\ \vdots & 0 & 0 & e^{0} \\ \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & \cdots & 0 \end{pmatrix}$$



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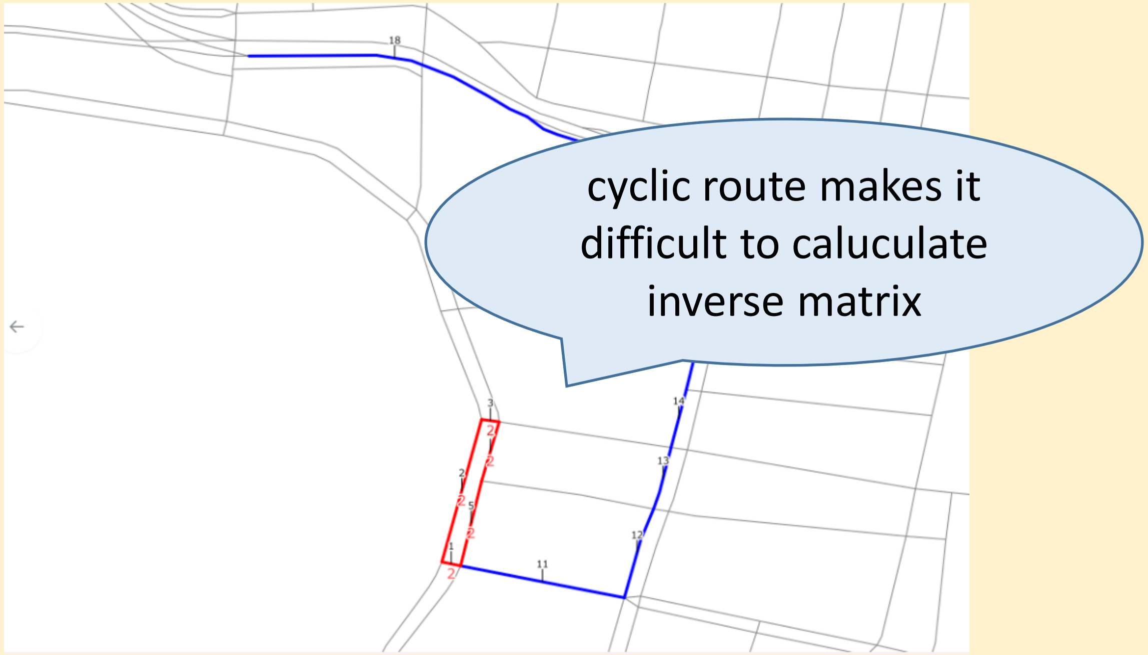


4.NEWPOINT

Recursive Logit Model

The infinite number of route alternatives is assumed
(including cyclic route)

Restrict to more feasible link

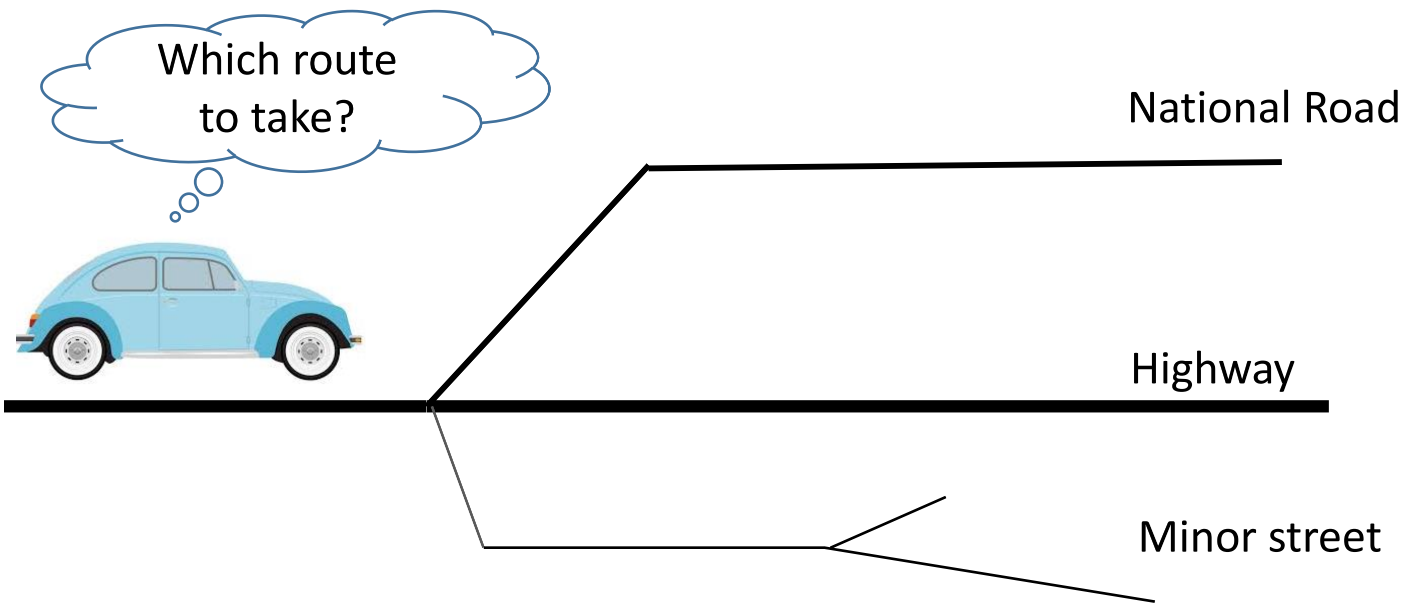
Make the former step of choosing choice set
Cascetta et al. (2001)

4.NEWPOINT

Restrict to more feasible route

Make the former step of choosing choice set
(Cascetta et al. 2001)

Using Link Perception



4.NEWPOINT

Restrict to more feasible route in path based model

IAP (Cascetta et al. 2001)

(the Perception/Availability of alternative Implicitly in the choice model)

$$U_j^n = V_j^n + \ln \mu_C^n(j) + \varepsilon_j^n$$

U_j^n : Total utility of alternative j for dicision maker n

V_j^n : systematic utility of alternative j for dicision maker n

$\mu_C^n(j)$: the degree of membership of alternative j to the fuzzy choice set C for dicision-maker n ($0 \leq \mu_C^n \leq 1$)

ε_j^n : the random residual of alternative j for dicision maker n

4.NEWPOINT

Restrict to more feasible route in link based model

IAP (Cascetta et al. 2001)

(the perception/availability of alternative implicitly in the choice model)

- Instantaneous utility $v(a|k)$
  the sum of deterministic utility and stochastic utility

$$u_n(a|k) = v_n(a|k) + ln\mu_C^n(k) + \varepsilon_n(a)$$

u_n : Total instantaneous utilityfor dicision maker n

$v_n(a|k)$: deterministic link utility of alternative k for dicision maker n

$\mu_C^n(k)$: the degree of membership of alternative link k to the fuzzy choice set C for dicision-maker n ($0 \leq \mu_C^n(k) \leq 1$)

ε_n : the random residual of alternative j for dicision maker i

4.NEWPOINT

Restrict to more feasible route in link based model

IAP (Cascetta et al. 2001)

(the perception/availability of alternative implicitly in the choice model)

◆ Instantaneous utility $v(a|k)$

the sum of deterministic utility and stochastic utility

$$u_n(a|k) = v_n(a|k) + ln\mu_C^n(k) + \varepsilon_n(a)$$

The factor of perception

Ex.) Road type, the number of lane , ect

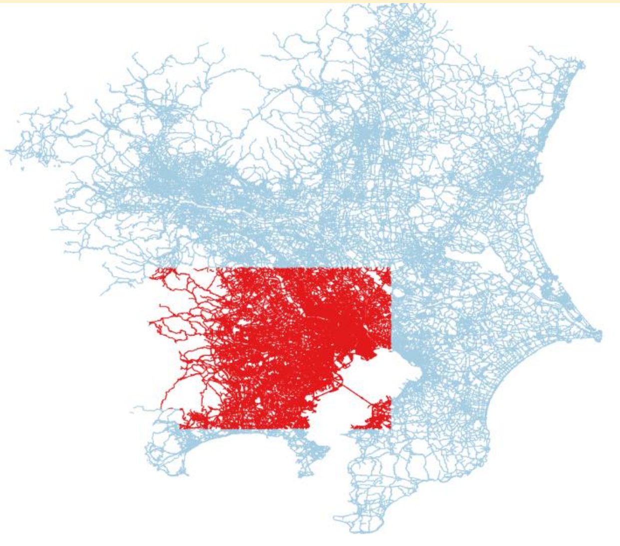
5.DATA

Trip Data

ETC 2.0(trajectory data)
Electronic Toll Collection System

Network Data

DRM
Digital Road Map

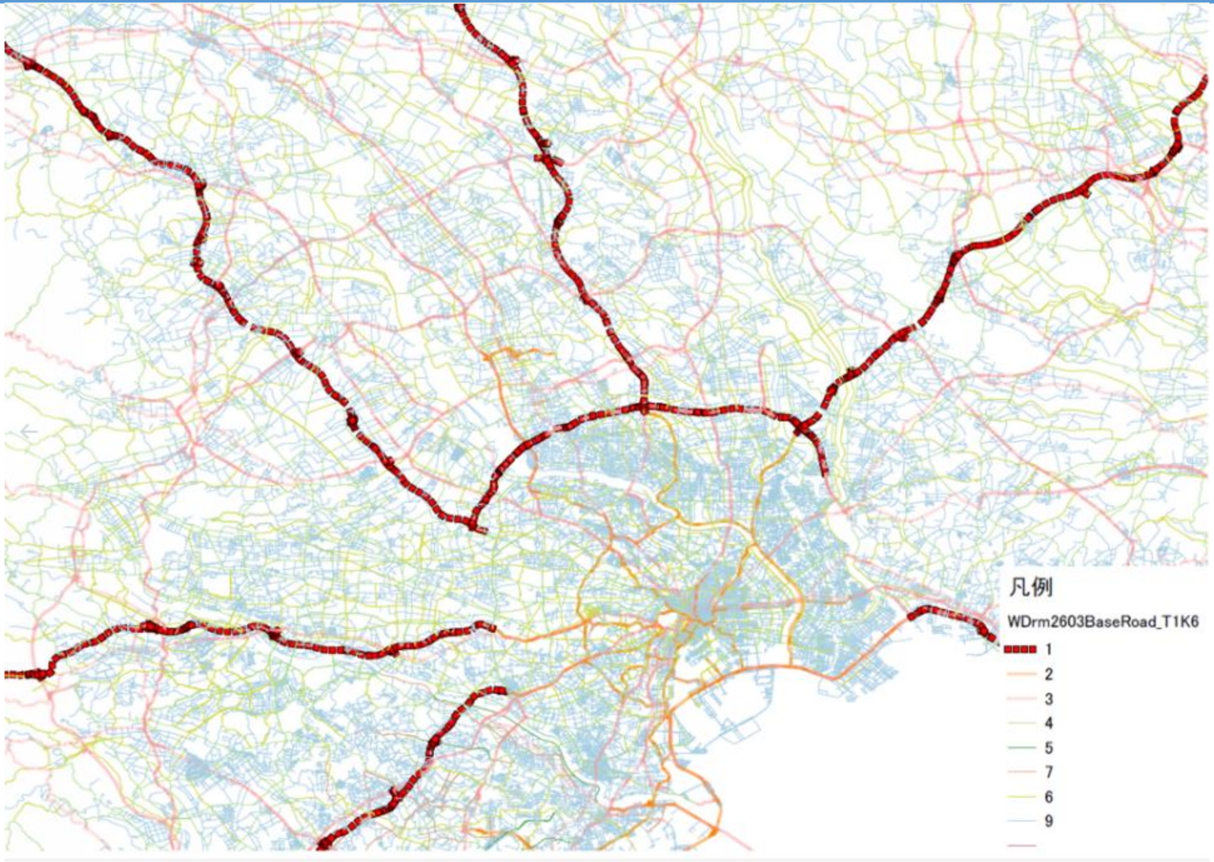


5.TRIPDATA

- Conducted by Ministry of Land Infrastructure and Transport
- Probe data
- All of the private vehicle route with ETC2.0
- The data of 24 hours a day, 365 days a year
- The data include

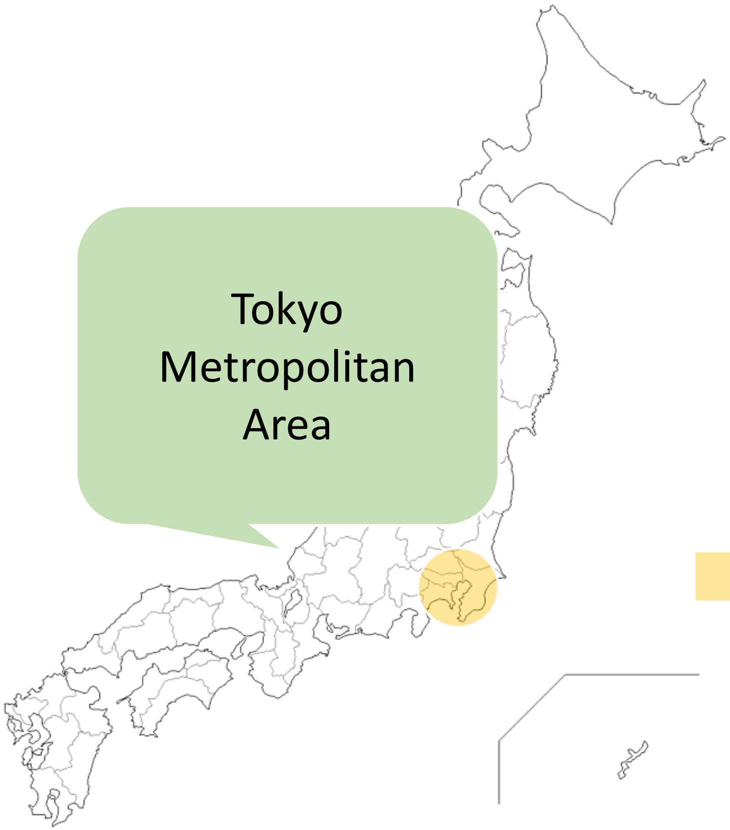
  Car ID ,Car kind , time , GPS information ...

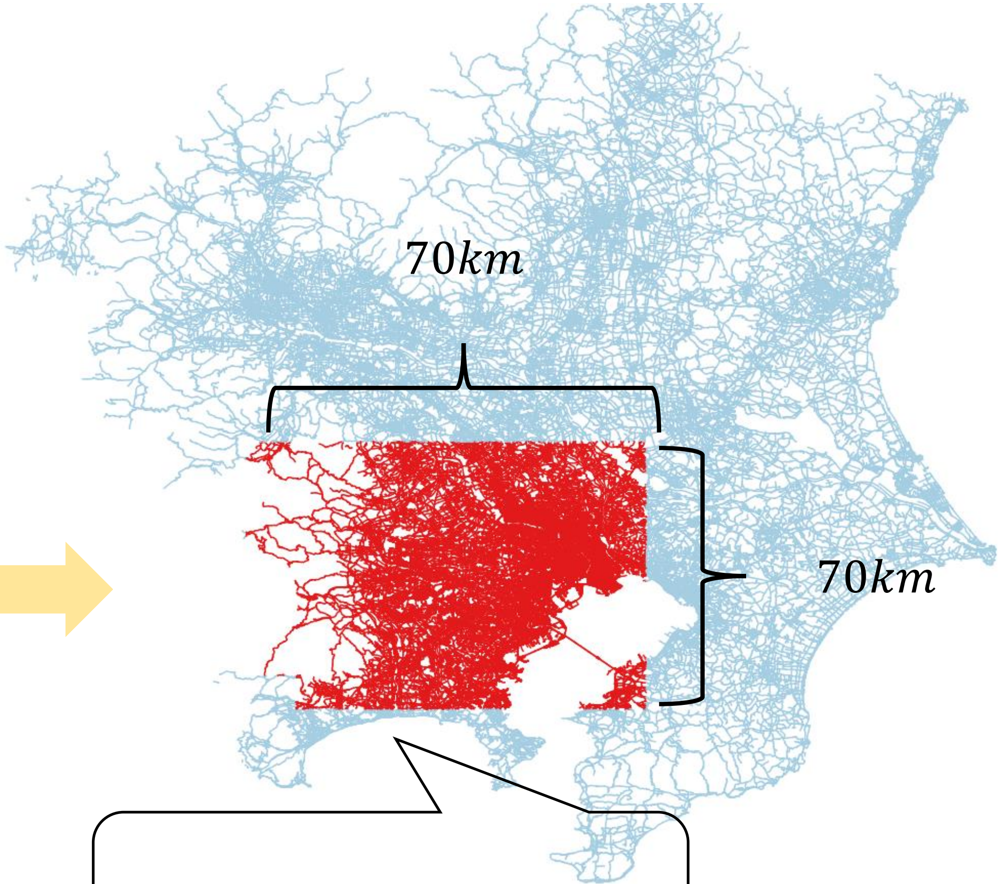
5.NETWORK DATA



- Made by The Japan Digital Road Map Associaton
- It include road information
  Ex) road type, Road Length, GIS Information…
- Additional Information by IBS(transport consultant)
  Ex) Road cost, Time, traffic light…

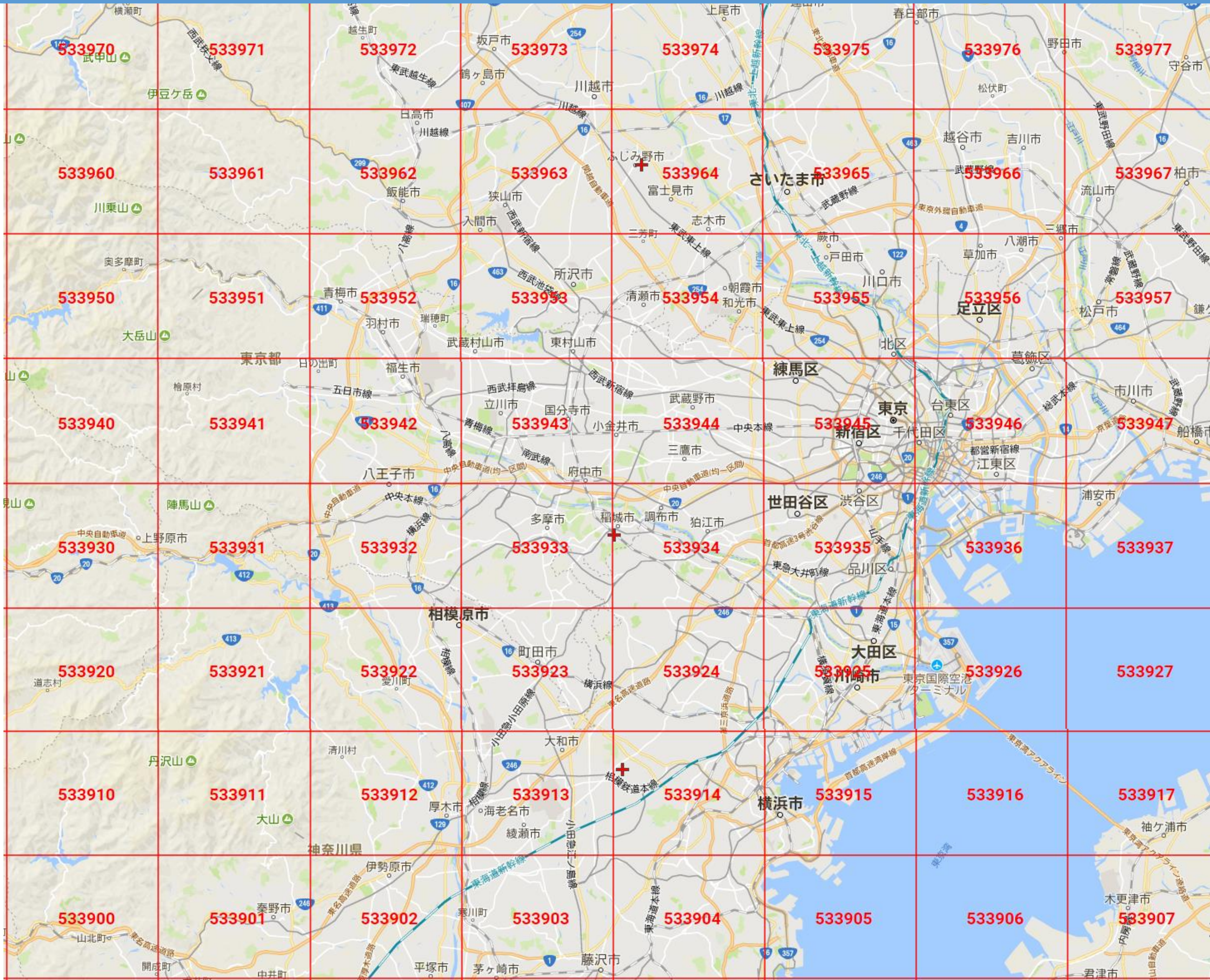
5.TARGET AREA



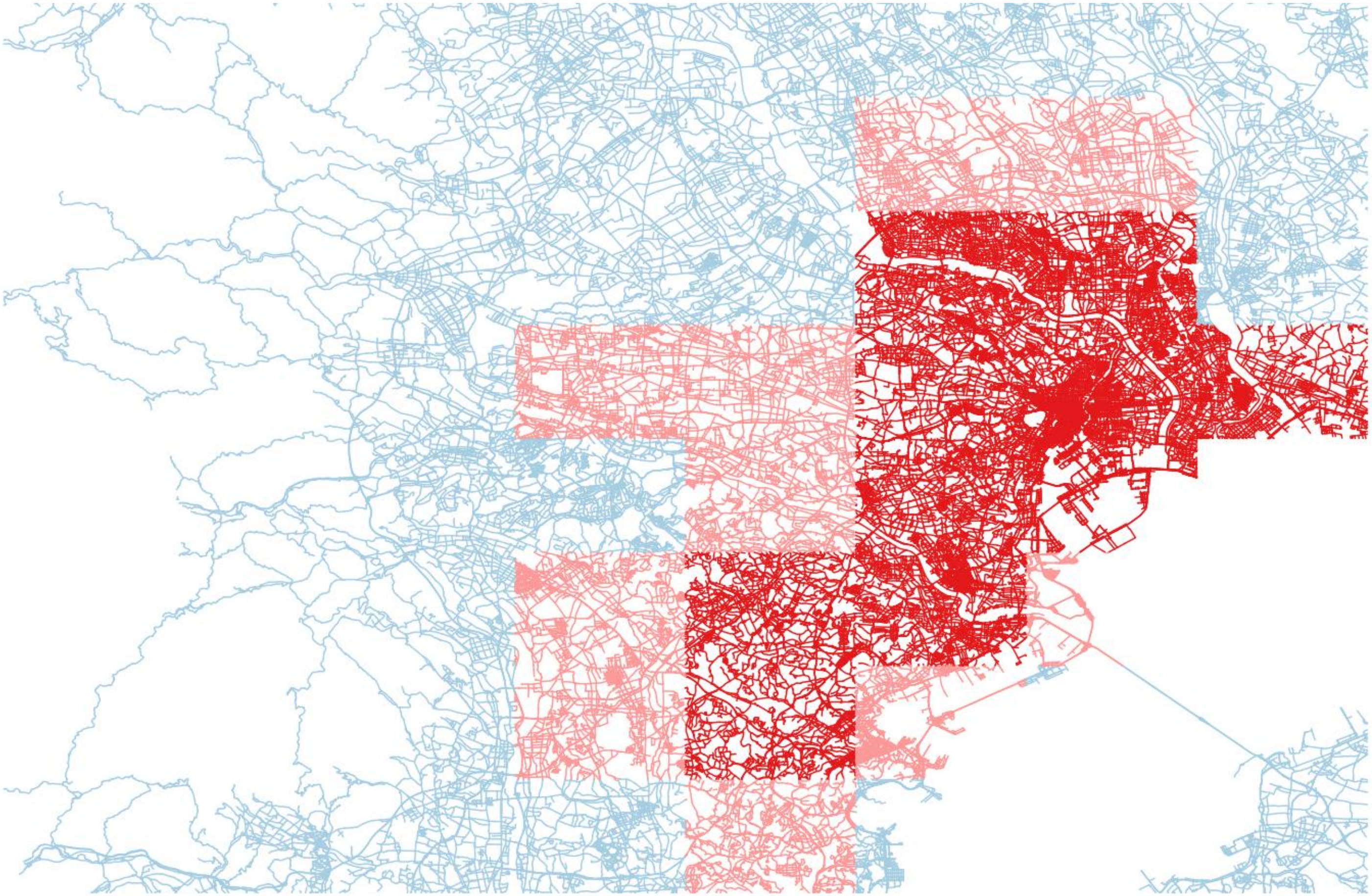


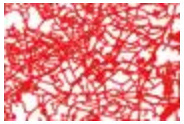
#link	228387

5.TARGET AREA



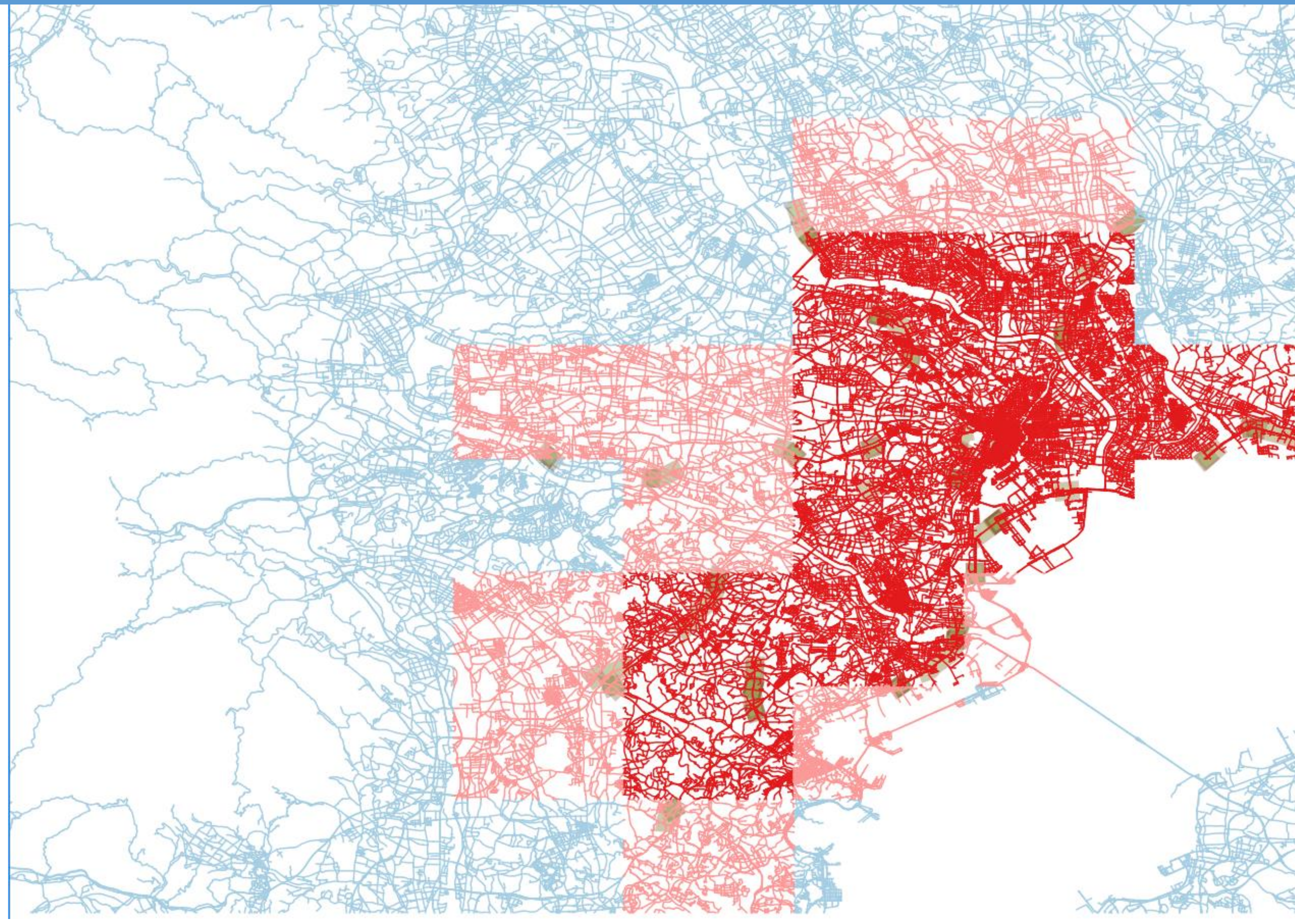
5.SETTING DESTINATION



 … Congested Area Top 10 → … each 5 destination (total 50)

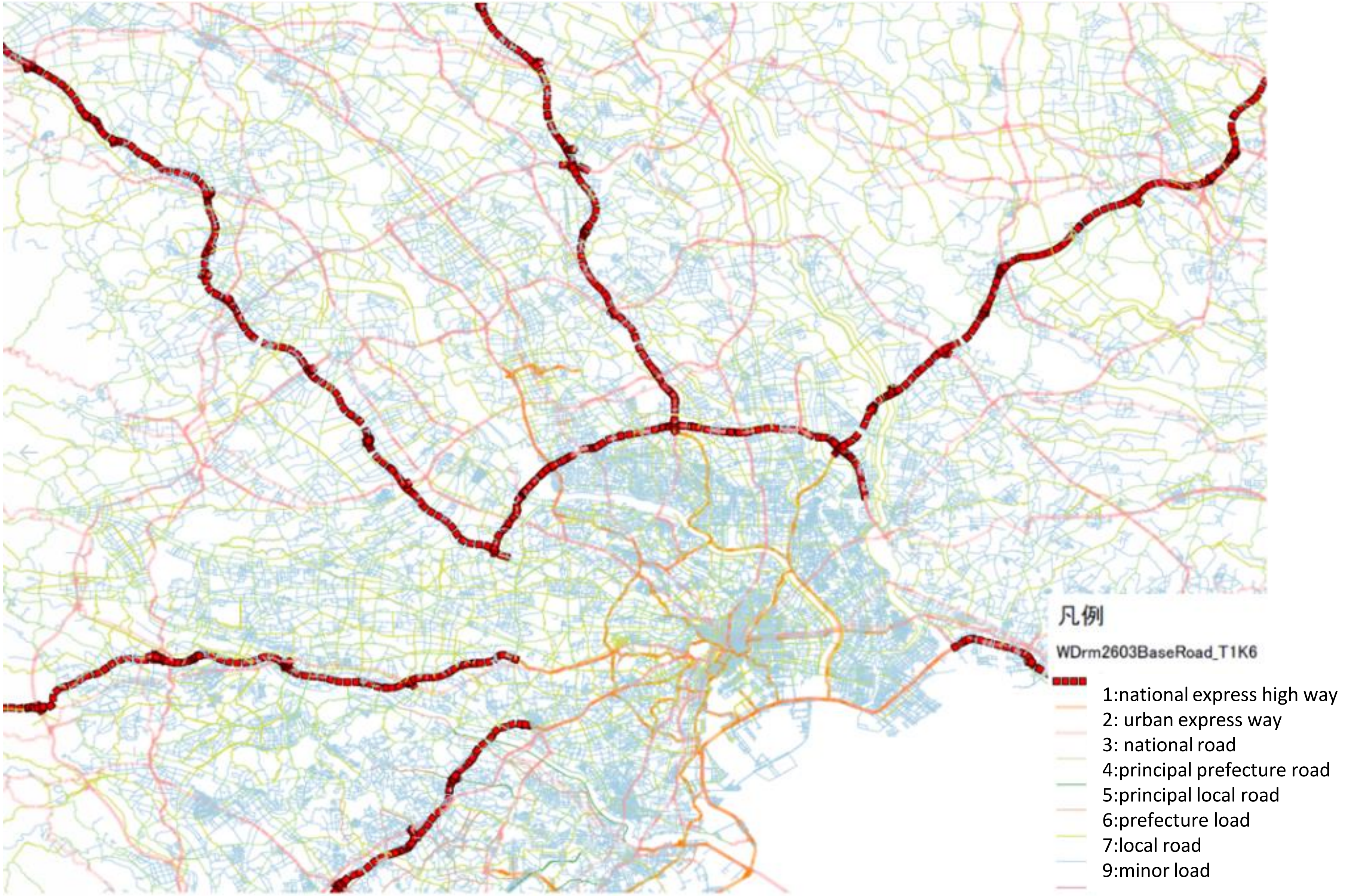
 … congested Area Top 20 → … each 2 destination (total 20)

5.NETWORK DATA



… destination node (congested area in the target mesh)
total : 70 destination

5.NETWORK DATA



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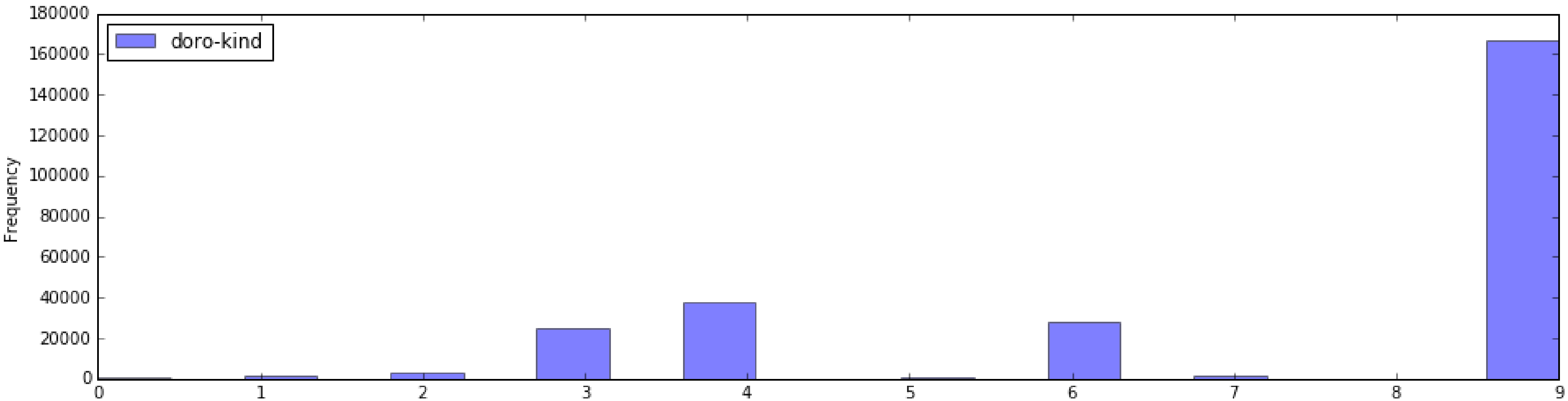
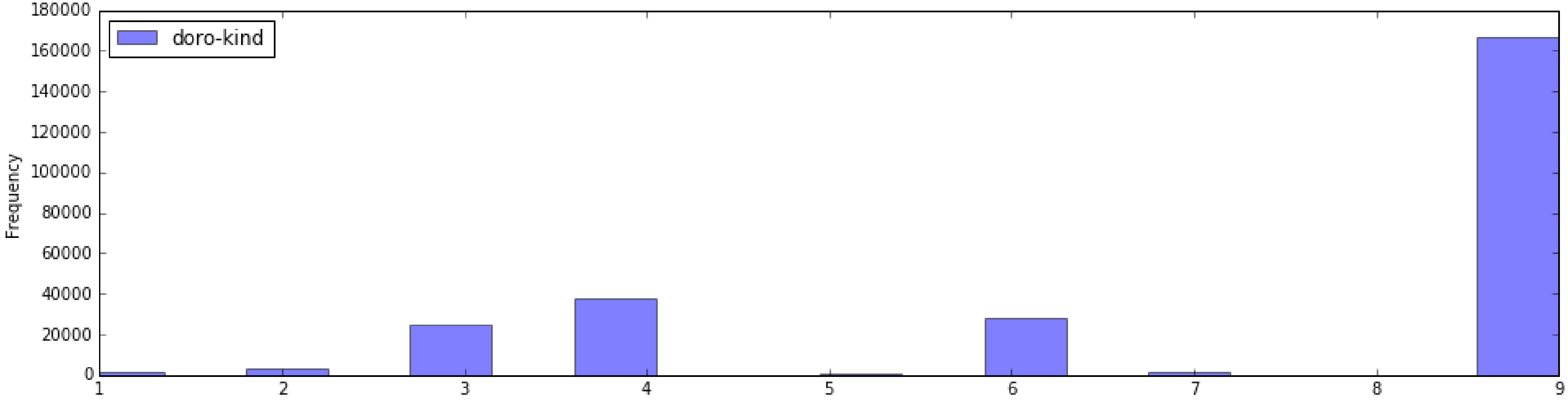
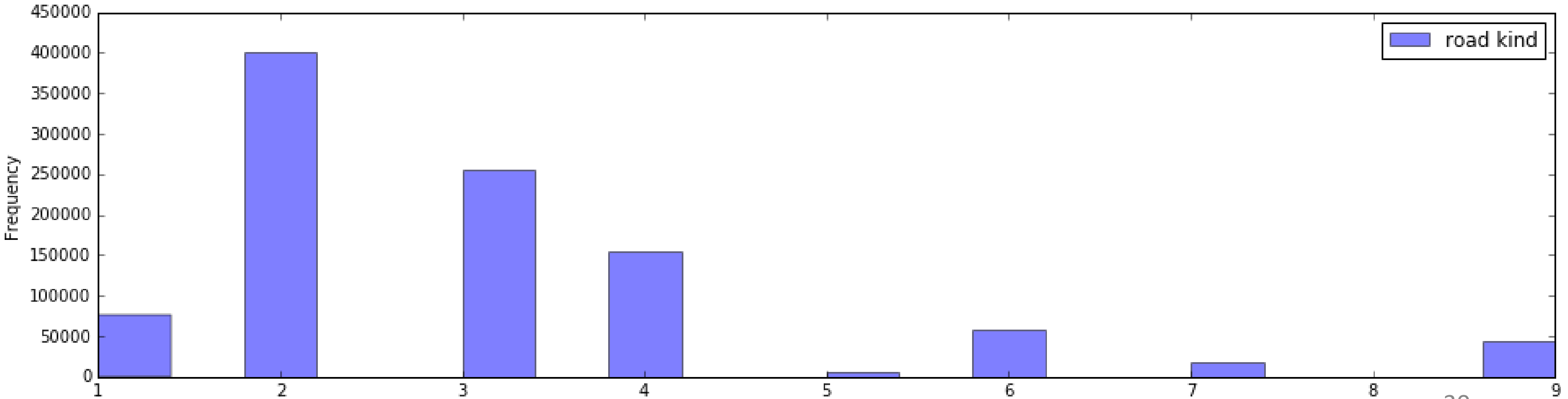


5.NETWORK DATA

- **The road type distribution of all of the network**

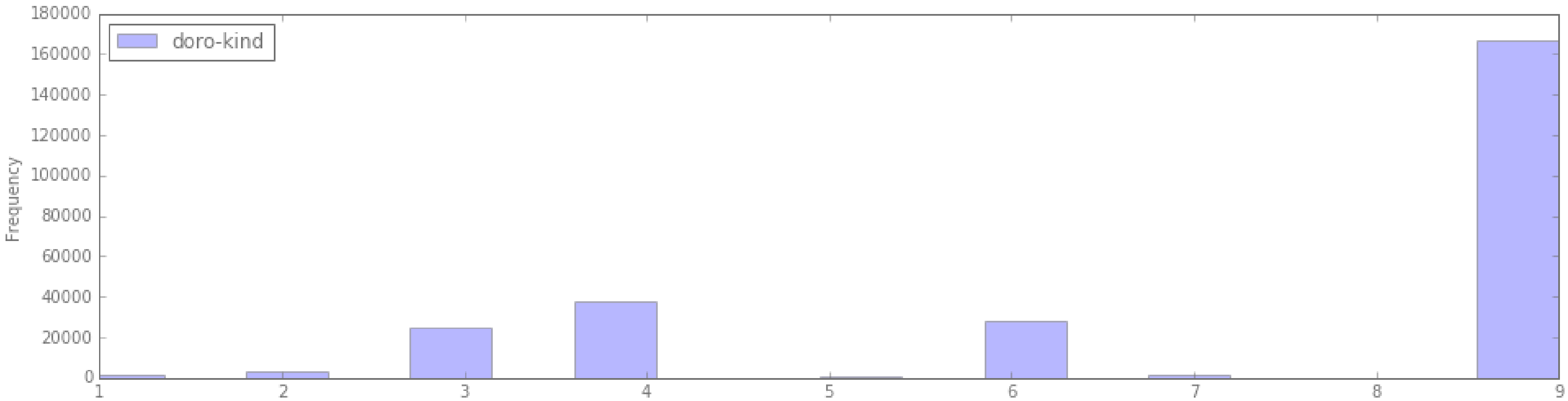


- **The road type distribution of only used network**

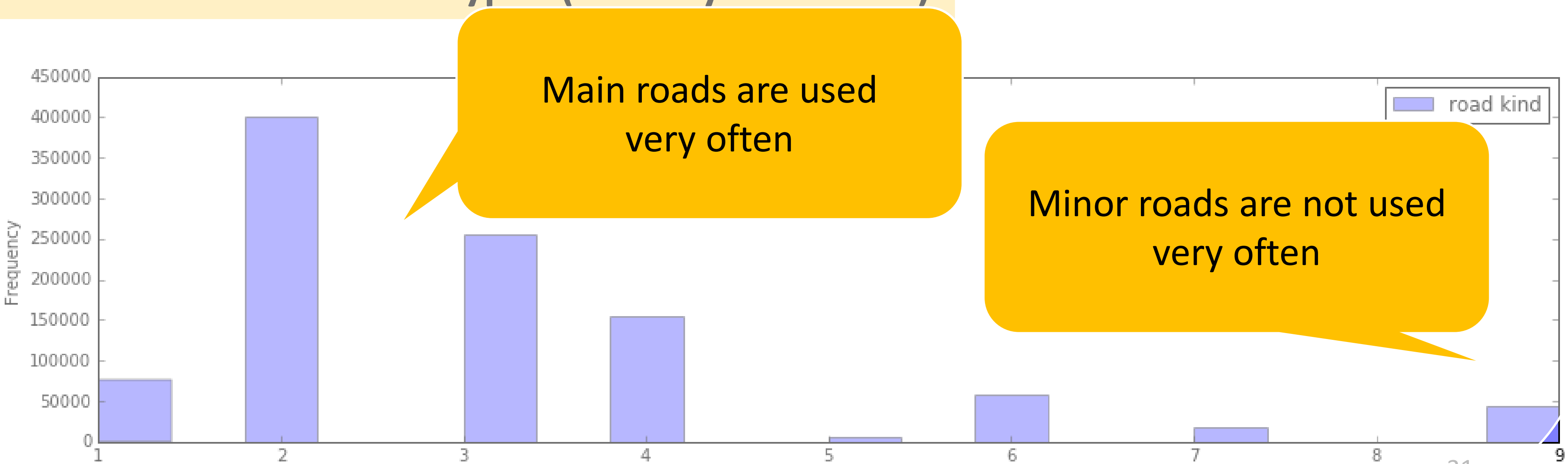


5.NETWORK DATA

- Distribution of road types (all of the network)

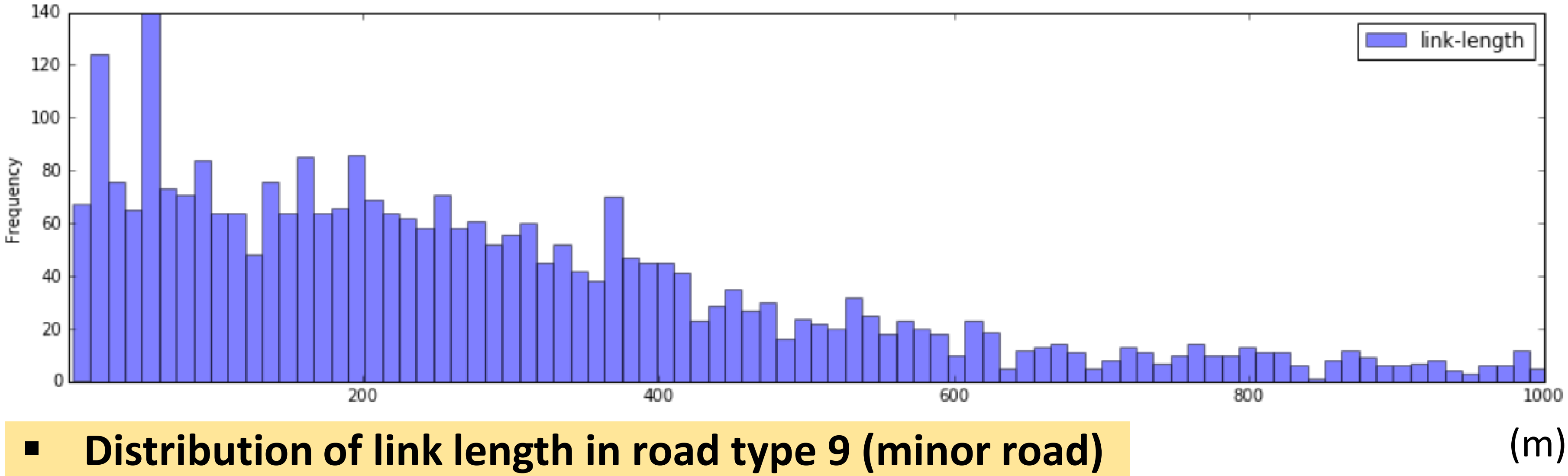


- Distribution of road types (actually used links)

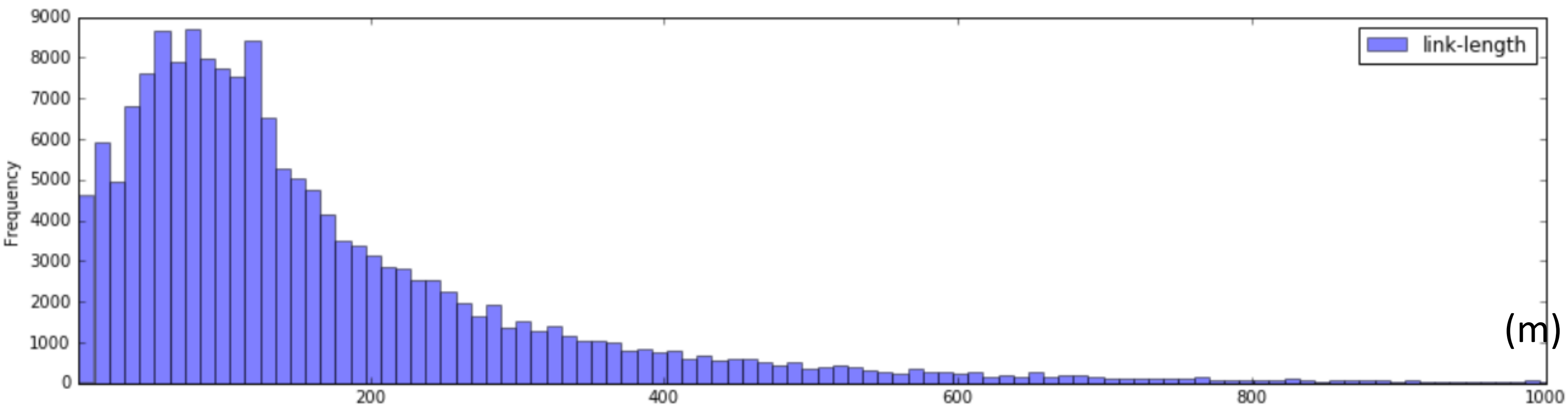


5.NETWORK DATA

- **Distribution of link length in road type 2 (main road)**



- **Distribution of link length in road type 9 (minor road)**



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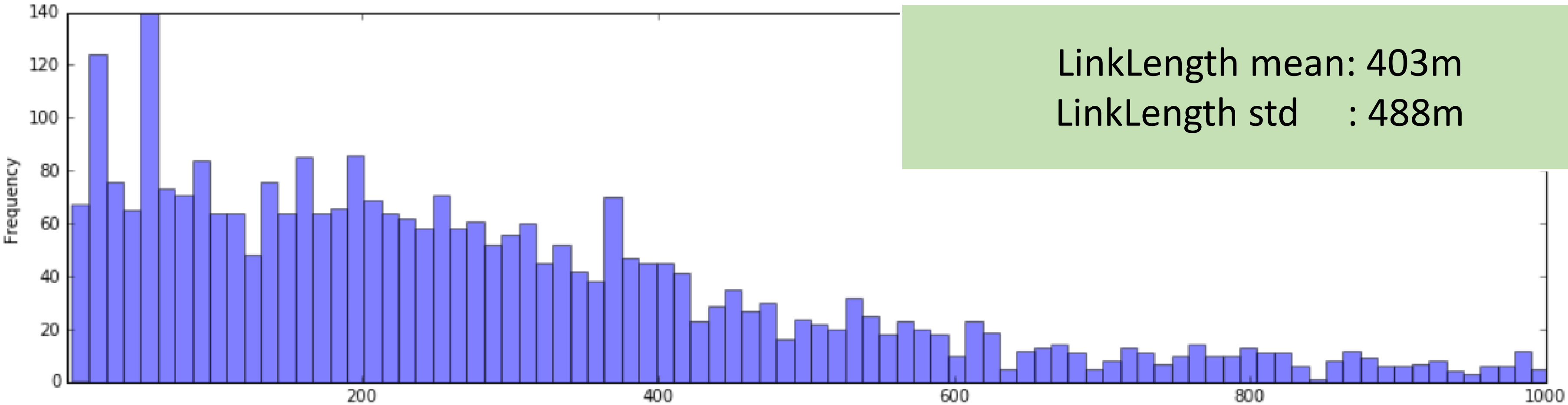
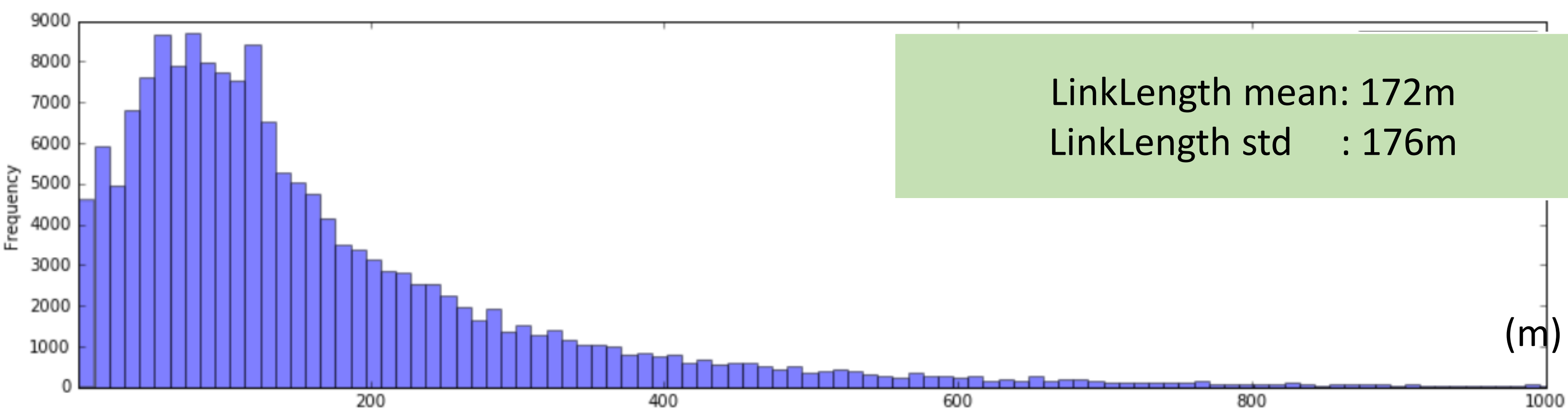


LinkLength mean: 403m
LinkLength std : 488m

(m)

- **Distribution of link length in road type 9 (minor road)**

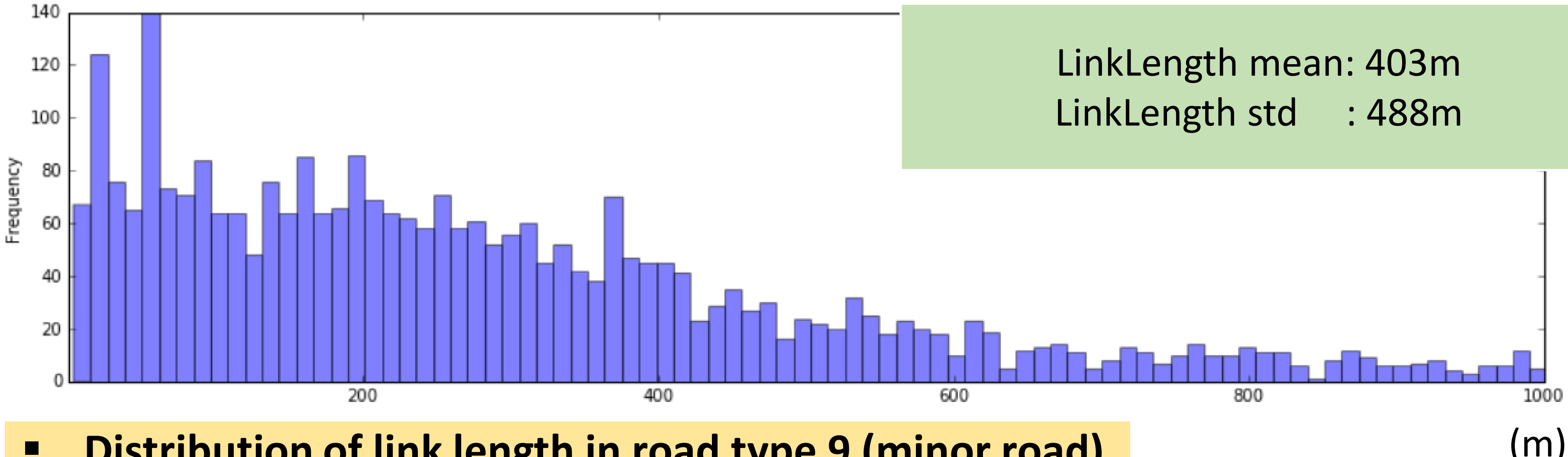


LinkLength mean: 172m
LinkLength std : 176m

(m)

5.NETWORK DATA

- **Distribution of link length in road type 2 (main road)**



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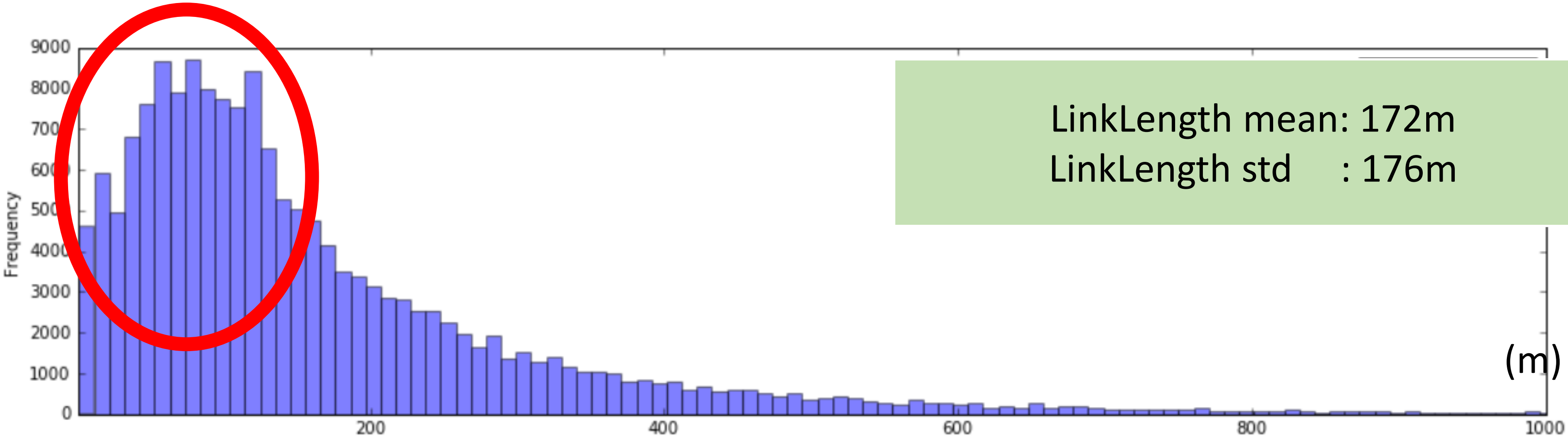
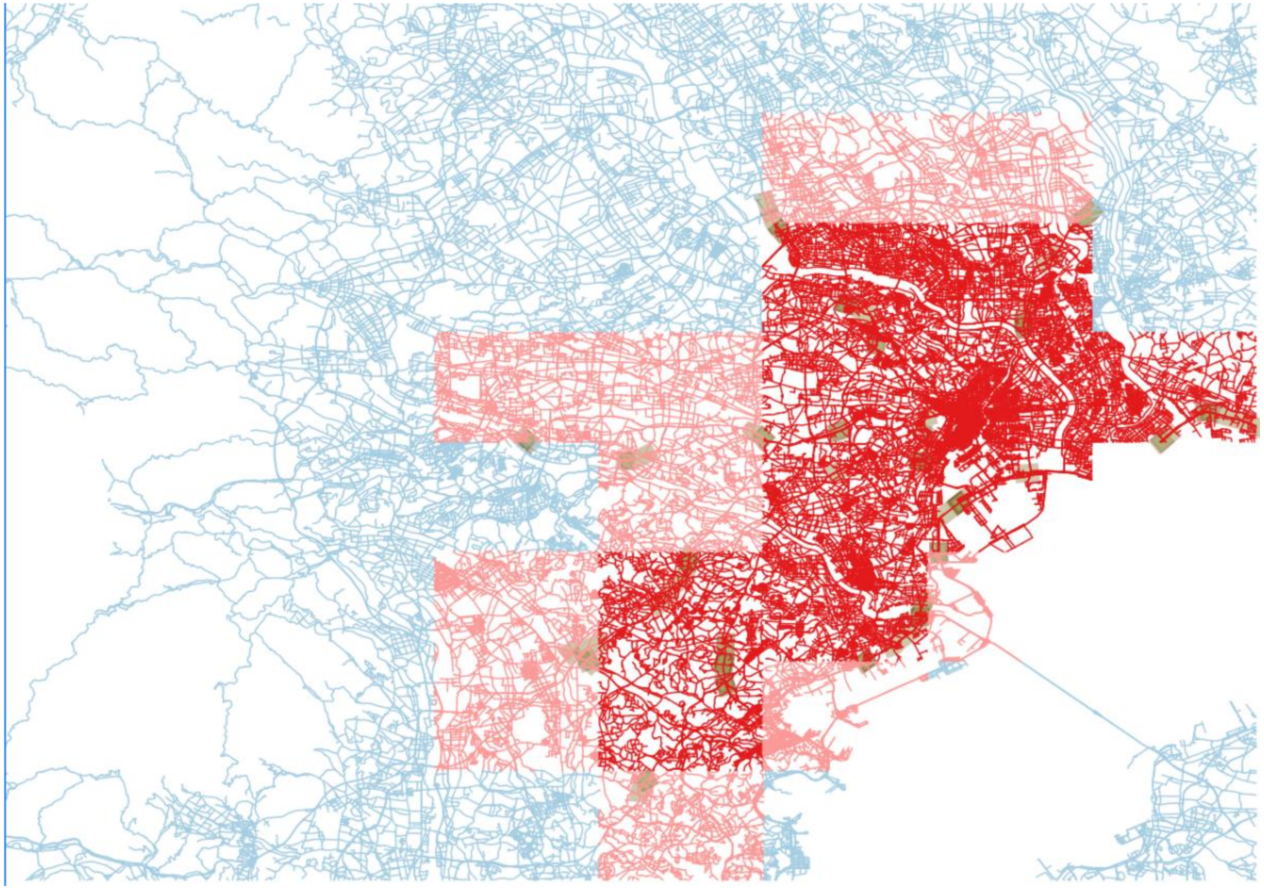


LinkLength mean: 172m
LinkLength std : 176m

5.TRIP DATA



Date : 2016.10.16 (sun)
Destination # : 70
link # : 264685
Trip # : 13449
Choice average # :75.2

6.RESULT SO FAR …apply to large area

- **How to define perception term**

$$v_n(a|k) = \beta_{time}x_{time} + \beta_{width}x_{width} + \beta_{Uturn}Uturn + \beta_{Rturn}Rturn + ln\mu(k) + ASC$$

The number of lane

Road type

0	0	0.5	1	1.5	2	2.5	3	4	5	6
0	1	1	1	1	2	2	2	2	3	3
2	5	5	5	5	6	6	6	6	7	7
3	4	4	4	4	5	5	5	5	6	6
4	3	3	3	3	4	4	4	4	5	5
6	2	2	2	2	3	3	3	3	4	4
9	1	1	1	1	2	2	2	2	3	3

$$perception\ \text{term}\ \ \mu = \text{X}/7$$

$$1/7 \leq \mu \leq 1$$

6.RESULT SO FAR …apply to large ara

Model1 (Without perception)

$$v_n(a|k) = \beta_{time}x_{time} + \beta_{width}x_{width} + \beta_{Uturn}Uturn + \beta_{Rturn}Rturn + ASC$$

Model1 (With perception)

$$v_n(a|k) = \beta_{time}x_{time} + \beta_{width}x_{width} + \beta_{Uturn}Uturn + \beta_{Rturn}Rturn + ln\mu(k) + ASC$$

6.RESULT SO FAR …apply to large area

Model1 (without perception)

$parameter$	$Value$	$T - value$
β_{time}	1.19	11.0
β_{width}	-1.30	-2.29
β_{Uturn}	-28.2	-0.16
β_{Rturn}	-10.04	-0.50
$sample\ size$	13449	
$Max\ LL$	-753471	
$estimation\ time\ (s)$	26404	

Model2 (with perception)

$parameter$	$Value$	$T - value$
β_{time}	-1.00	-7.23
β_{width}	-0.61	-0.81
β_{Uturn}	-1789	-0.08
β_{Rturn}	-2.24	-0.60
$\beta_{perception}$	$1(fixed)$	
$sample\ size$	13449	
$Max\ LL$	-1422210	
$estimation\ time\ (s)$	23600	

6.RESULT SO FAR …apply to large area

Model1 (without perception)

$parameter$	$Value$	$T-value$
β_{time}	1.19	11.0
β_{width}	-1.30	-2.29
β_{Uturn}	[illegible]	-0.16
β_{Rturn}	[illegible]	[illegible]
$sample\ size$	[illegible]	
$Max\ LL$	[illegible]	
$estimation\ time\ (s)$	26404	

positive

Model2 (with perception)

$parameter$	$Value$	$T-value$
β_{time}	-1.00	-7.23
β_{width}	-0.61	-0.81
β_{Uturn}	[illegible]	-0.08
β_{Rturn}	[illegible]	[illegible]
$\beta_{perception}$	[illegible]	[illegible]
$sample\ size$	[illegible]	
$Max\ LL$	-1422210	
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$\beta_{perception}$	[illegible]	[illegible]
$sample\ size$	[illegible]	
$Max\ LL$	[illegible]	
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Estimation time is improved

6.RESULT SO FAR …apply to large area

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β_{Rturn}	-2.24	-0.60
$\beta_{perception}$	$1(fixed)$	
$sample\ size$	13449	
$Max\ LL$	-1422210	
$estimation\ time\ (s)$	23600	

Max LL is improved

6.RESULT SO FAR …apply to large area

Model1 (without perception)

$parameter$	$Value$	$T-value$
β_{time}	1.19	11.0
β_{width}	-1.30	-2.29
β_{Uturn}	-28.2	-0.16
β_{Rturn}	-10.04	-0.50
$sample\ size$	13449	
$Max\ LL$	-753471	
$estimation\ time\ (s)$	26404	

Model2 (with perception)

$parameter$	$Value$	$T-value$
β_{time}	-1.00	-7.23
β_{width}	-0.61	-0.81
β_{Uturn}	-1789	-0.08
β_{Rturn}	-2.24	-0.60
$\beta_{perception}$	$1(fixed)$	
$sample\ size$	13449	
$Max\ LL$	-1422210	
$estimation\ time\ (s)$	23600	

6.RESULT SO FAR ...apply to large area

Model1 (without perception)

$parameter$	$Value$	$T-value$
β_{time}	1.19	11.0
β_{width}	-1.30	-2.29
β_{Uturn}	-28.2	-0.16
β_{Rturn}	-10.04	-0.50
$sample\ size$	13449	
$Max\ LL$	-753471	
$estimation\ time\ (s)$	26404	

Model2 (with perception)

$parameter$	$Value$	$T-value$
β_{time}	-1.00	-7.23
β_{width}	-0.61	-0.81
β_{Uturn}	-1789	-0.08
β_{Rturn}	-2.24	-0.60
$\beta_{perception}$	$1(fixed)$	
$sample\ size$	13449	
$Max\ LL$	-1422210	
$estimation\ time\ (s)$	23600	

Estimation time is improved

6.RESULT SO FAR …apply to small area

$20\ km$ (horizontal) × $20\ km$ (vertical)

$parameter$	$Value$	$T-value$
β_{time}	1.19	11.0
β_{width}	-1.30	-2.29
β_{Uturn}	-28.2	-0.16
β_{Rturn}	-10.04	-0.50
$sample\ size$	13449	
$Max\ LL$	-753471	
$estimation\ time\ (s)$	26404	

Day 2016.10.16 (Sun)
Trip # 2120
Link # 56897
Destination # 10

6.RESULT SO FAR …apply to small area

$parameter$	$Value$	$T-value$
β_{time}	1.19	11.0
β_{width}	-1.30	-2.29
β_{Uturn}	-28.2	-0.16
β_{Rturn}	-10.04	-0.50
$sample\ size$	13449	
$Max\ LL$	-753471	
$estimation\ \ time\ (s)$	26404	

Model1 (without perception)

$$v_n(a|k) = \beta_{time}x_{time} + \beta_{length}x_{length} + \beta_{cost}x_{cost} + \beta_{width}x_{width} + \beta_{Uturn}Uturn + \beta_{Rturn}Rturn + constant$$

Model2 (with perception)

$$v_n(a|k) = \beta_{time}x_{time} + \beta_{length}x_{length} + \beta_{cost}x_{cost} + \beta_{width}x_{width} + \beta_{Uturn}Uturn + \beta_{Rturn}Rturn + ln\mu(k) + constant$$

6.RESULT SO FAR …apply to small area

model1

$parameter$	$Value$	$T - value$
β_{time}	-3.74	-13.86
β_{length}	-1.12	-33.79
β_{cost}	-3.65	-50.25
β_{width}	2.09	10.82
β_{Uturn}	-623	-0.24
β_{Rturn}	-38.7	-136
$sample\ size$	1039	
$Max\ LL$	-1520211	
$estimation\ time\ (s)$	1850	

model2

$parameter$	$Value$	$T - value$
β_{time}	-4.21	-11.3
β_{length}	-1.14	-2.67
β_{cost}	-3.20	-3470
β_{width}	2.09	16.7
β_{Uturn}	-563	-1.01
β_{Rturn}	-39.5	38.3
$\beta_{perception}$	$1(fixed)$	
$sample\ size$	1039	
$Max\ LL$	-1082644	
$estimation\ time\ (s)$	1368	

6.RESULT SO FAR …apply to small area

model1

$parameter$	$Value$	$T-value$
β_{time}	-2.187	-13.86
β_{length}	-3.607	-33.79
β_{cost}	-2.169	-50.25
β_{width}	1.693	10.82
β_{Uturn}	-563	-0.24
β_{Rturn}	-49.54	-136
$sample\ size$	1039	
$Max\ LL$	-1439386	
$estimation\ \ time$	8497	

model2

$parameter$	$Value$	$T-value$
β_{time}	-3.068	-29.3
β_{length}	-4.740	-7.91
β_{cost}	-2.061	-34.2
β_{width}	1.433	11.8
β_{Uturn}	-756.8	-287
β_{Rturn}	-48.44	-174
$\beta_{perception}$	1(fixed)	
$sample\ size$	1039	
$Max\ LL$	-1330211	
$estimation\ \ time$	1368	

6.RESULT SO FAR …apply to small area

model1

$parameter$	$Value$	$T - value$
β_{time}	-2.187	-13.86
β_{length}	-3.607	-33.79
β_{cost}	-2.169	-50.25
β_{width}	1.693	10.82
β_{Uturn}	-563	-0.24
β_{Rturn}	-49.54	-136
$sample\ size$	1039	
$Max\ LL$	-1439386	
$estimation\ \ time$	8497	

model2

$parameter$	$Value$	$T - value$
β_{time}	-3.068	-29.3
β_{length}	-4.740	-7.91
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β_{width}	1.433	11.8
β_{Uturn}	-756.8	-287
β_{Rturn}	-48.44	-174
$\beta_{perception}$	1.29	85.8
$sample\ size$	1039	
$Max\ LL$	-1330211	
$estimation\ \ time$	1368	

7.CONCLUSION and FUTURE WORKS

Conclusion

1. Route choice model in large area are created using link based model
2. Adding the step of choosing choice set, the estimation of RL can be more easily and stability and increase accuracy of estimation

Future works

1. Including non link-additive term like cost as explanatory variables
2. Including perception term more precisely
3. Including explanatory variables more in large network

RESULT SO FAR …apply to small area

$20\ km$

$20\ km$

$parameter$	$Value$	$T-value$
β_{time}	1.19	11.0
β_{width}	-1.30	-2.29
β_{Uturn}	-28.2	-0.16
β_{Rturn}	-10.04	-0.50
$sample\ size$	13449	
$Max\ LL$	-753471	
$estimation\ time\ (s)$	26404	

Day 2016.10.16 (Sun)
Trip # 2120
Link # 56897
Destination # 10

RESULT SO FAR …apply to small area

$parameter$	$Value$	$T-value$
β_{time}	1.19	11.0
β_{width}	-1.30	-2.29
β_{Uturn}	-28.2	-0.16
β_{Rturn}	-10.04	-0.50
$sample\ size$	13449	
$Max\ LL$	-753471	
$estimation\ \ time\ (s)$	26404	

Model1 (without perception)

$$v_n(a|k) = \beta_{time}x_{time} + \beta_{length}x_{length} + \beta_{cost}x_{cost} + \beta_{width}x_{width} + \beta_{Uturn}Uturn + \beta_{Rturn}Rturn + constant$$

Model2 (with perception)

$$v_n(a|k) = \beta_{time}x_{time} + \beta_{length}x_{length} + \beta_{cost}x_{cost} + \beta_{width}x_{width} + \beta_{Uturn}Uturn + \beta_{Rturn}Rturn + ln\mu(k) + constant$$

RESULT SO FAR ...apply to small area

model1

$parameter$	$Value$	$T - value$
β_{time}	-3.74	-13.86
β_{length}	-1.12	-33.79
β_{cost}	-3.65	-50.25
β_{width}	2.09	10.82
β_{Uturn}	-623	-0.24
β_{Rturn}	-38.7	-136
$sample\ size$	1039	
$Max\ LL$	-1520211	
$estimation\ \ time\ (s)$	1850	

model2

$parameter$	$Value$	$T - value$
β_{time}	-4.21	-11.3
β_{length}	-1.14	-2.67
β_{cost}	-3.20	-3470
β_{width}	2.09	16.7
β_{Uturn}	-563	-1.01
β_{Rturn}	-39.5	38.3
$\beta_{perception}$	$1(fixed)$	
$sample\ size$	1039	
$Max\ LL$	-1082644	
$estimation\ \ time\ (s)$	1368	

RESULT SO FAR ...apply to small area

model1

$parameter$	$Value$	$T - value$
β_{time}	-2.187	-13.86
β_{length}	-3.607	-33.79
β_{cost}	-2.169	-50.25
β_{width}	1.693	10.82
β_{Uturn}	-563	-0.24
β_{Rturn}	-49.54	-136
$sample\ size$	1039	
$Max\ LL$	-1439386	
$estimation\ \ time$	8497	

model2

$parameter$	$Value$	$T - value$
β_{time}	-3.068	-29.3
β_{length}	-4.740	-7.91
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$Max\ LL$	-1330211	
$estimation\ \ time$	1368	

RESULT SO FAR …apply to small area

model1

$parameter$	$Value$	$T - value$
β_{time}	-2.187	-13.86
β_{length}	-3.607	-33.79
β_{cost}	-2.169	-50.25
β_{width}	1.693	10.82
β_{Uturn}	-563	-0.24
β_{Rturn}	-49.54	-136
$sample\ size$	1039	
$Max\ LL$	-1439386	
$estimation\ ti$	8497	

model2

$parameter$	$Value$	$T - value$
β_{time}	-3.068	-29.3
β_{length}	-4.740	-7.91
β_{cost}	-2.061	-34.2
β_{width}	1.433	11.8
β_{Uturn}	-756.8	-287
β_{Rturn}	-48.44	-174
$\beta_{perception}$	1.29	85.8
$sample\ size$	1039	
$Max\ LL$	-1330211	
$estimation\ ti$	1368	