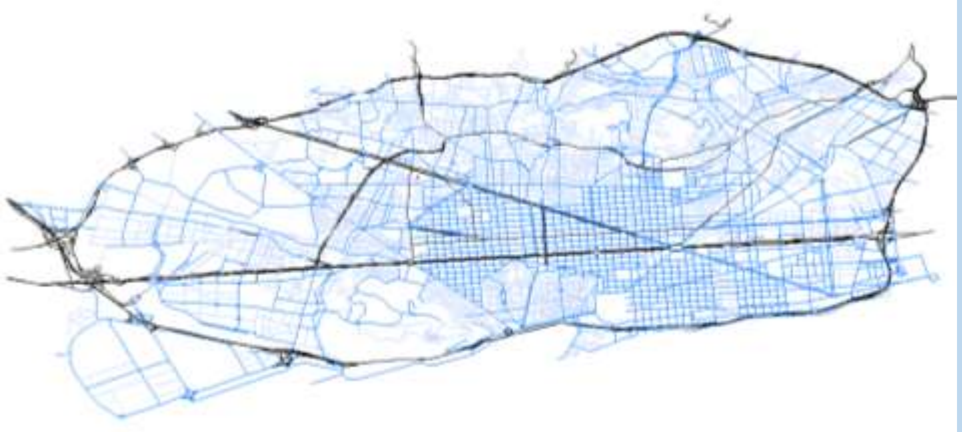
Transport modeling

Josep Maria Salanova Grau

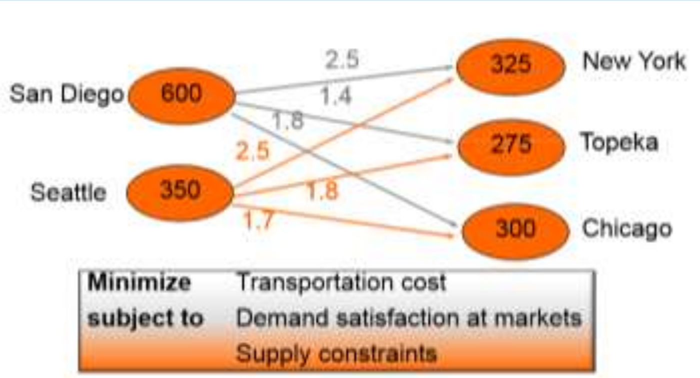
Evangelos Mintsis

Maria Chatziathanasiou



Introduction

“A model is a representation of something. It captures not all attributes of the represented thing, but rather only those seeming relevant. The model is created for a certain purpose and stakeholders.”



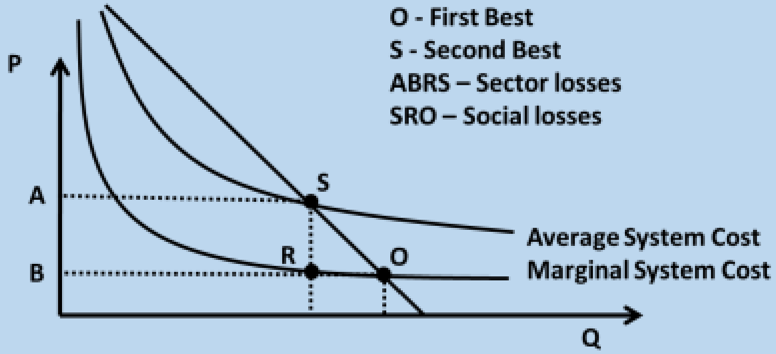
Mathematics! Economics!

$$\sum_{\substack{c,p:\\(c,p)\in\mathcal{N}}} tcost \cdot dist(c,p) \cdot x_p^c \rightarrow \min$$

$$\sum_{\substack{c,p:\\(c,p)\in\mathcal{N}}} x_p^c \leq sup(c) \quad \forall c$$

$$\sum_{\substack{c,p:\\(c,p)\in\mathcal{N}}} x_p^c \geq dem(p) \quad \forall p$$

$$x_p^c \geq 0 \quad \forall c,p : (c,p) \in \mathcal{N}$$

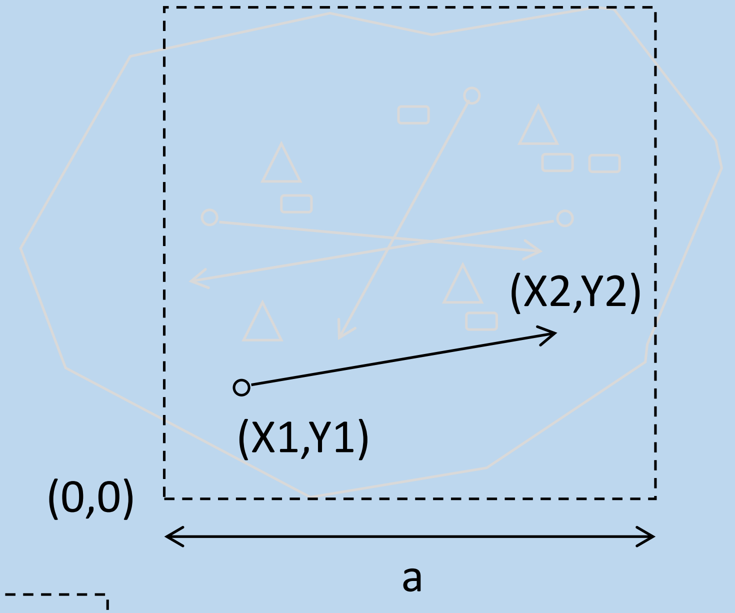


and code!

```
Positive Variable x ;

Equations
     cost        define objective function
     supply(i)   observe supply limit at plant i
     demand(j)   satisfy demand at market j ;
```

Geometry and probability

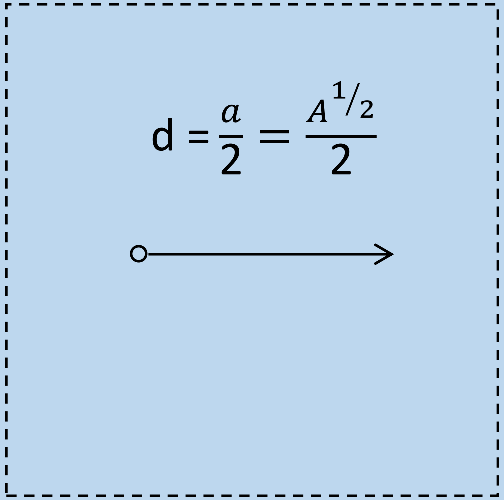


X_1 c (0,a)
Y_1 c (0,a)
X_2 c (0,a)
Y_1 c (0,a)

F(d)=Prob($(X_1-X_2)^2+(Y_1-Y_2)^2<d^2$)

$$E_{dist} = \int_0^{\sqrt{2}a} v g_v(v) dv$$

$$g(s) = \begin{cases} -2\frac{\sqrt{s}}{a^2b} - 2\frac{\sqrt{s}}{ab^2} + \frac{\pi}{ab} + \frac{s}{a^2b^2}, & 0 < s \le a^2\,; \\ -2\frac{\sqrt{s}}{a^2b} & \\ -\frac{1}{b^2} + \frac{2}{ab}\arcsin\left(\frac{a}{\sqrt{s}}\right) + \frac{2}{a^2b}\sqrt{s-a^2}, & a^2 < s \le b^2\,; \\ -\frac{1}{b^2} + \frac{2}{ab}\arcsin\left(\frac{a}{\sqrt{s}}\right) + \frac{2}{a^2b}\sqrt{s-a^2} & \\ -\frac{1}{a^2} + \frac{2}{ab}\arcsin\left(\frac{b}{\sqrt{s}}\right) + \frac{2}{ab^2}\sqrt{s-b^2} & \\ -\frac{\pi}{ab} - \frac{s}{a^2b^2}, & b^2 < s \le a^2+b^2. \end{cases}$$



$$d = \frac{a}{2} = \frac{A^{1/2}}{2}$$

$$E_{dist} = \frac{a}{3}\ln\left(1+\sqrt{2}\right) + \frac{a}{15}\left(2+\sqrt{2}\right) = 0.52140543a \approx 0.5a$$

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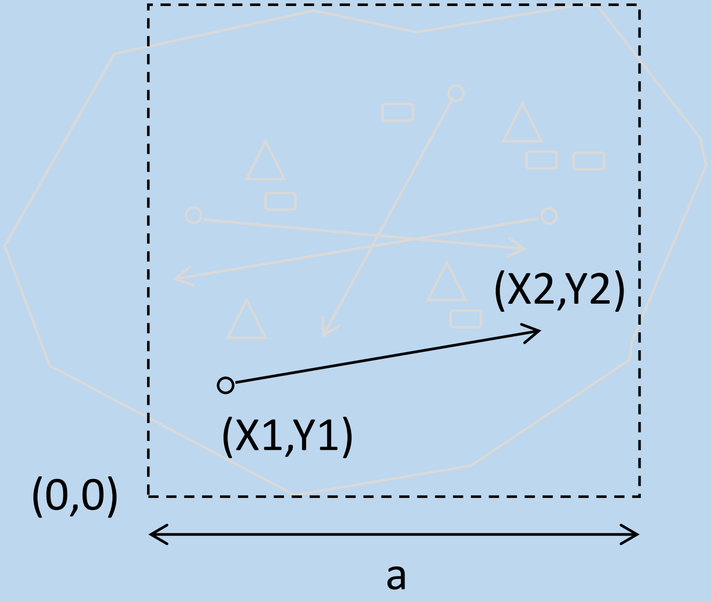
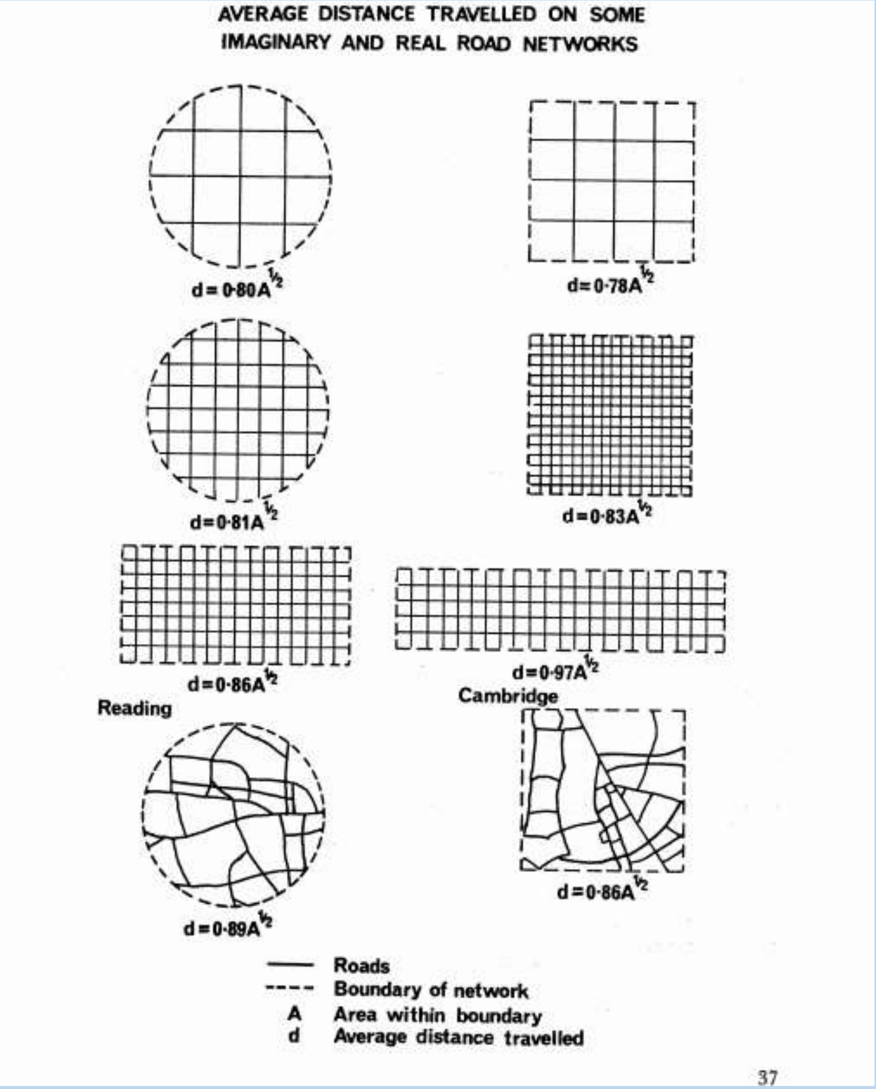
Geometry and probability

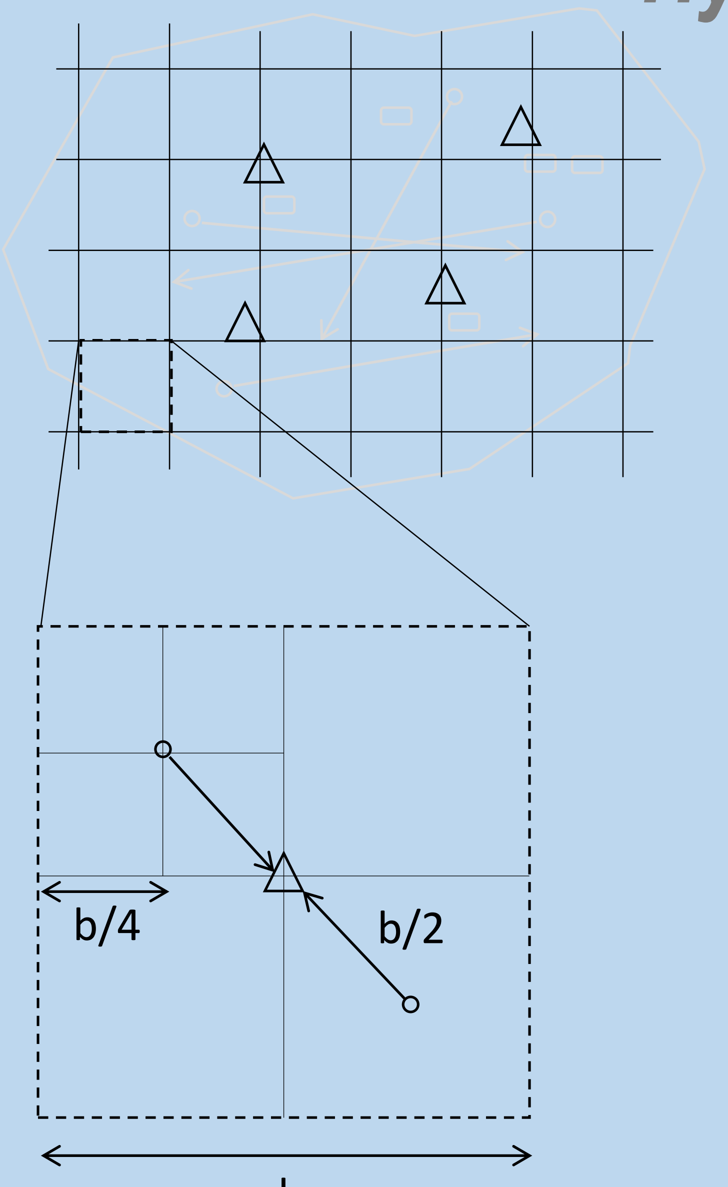


Network	Network parameter		
	Smeed	Holroyd	r
Direct distance		0.905	1.00
Radial		1.333	1.47
External ring		2.237	2.47
Internal ring		1.445	1.59
Radial arc		1.104	1.21
Rectangular	0.78 – 0.97	1.153	1.27
Triangular		0.998	1.1
Hexagonal		1.153	1.27
Irregular	0.80 – 1.06		



Hypotheses

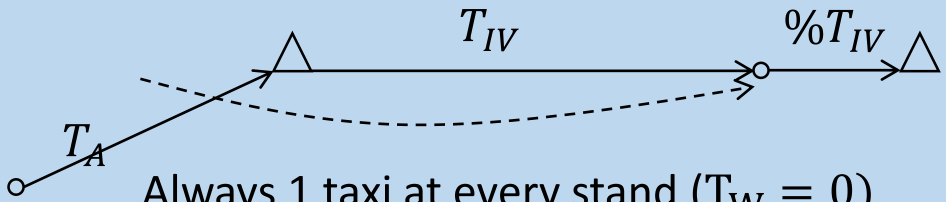
Number of stands = s = A/b^2



$$T_a = \frac{b}{2\bar{v}}$$

$$\text{offer (veh} - \text{klm)} = A \cdot \lambda_d$$
$$demand\ (veh - klm) = T_{IV} \cdot A \cdot \lambda_u$$

$$free\ veh - klm = A \cdot \lambda_d - T_{IV} \cdot A \cdot \lambda_u$$



Always 1 taxi at every stand ($T_W = 0$)

$$s = \frac{A}{b^2} = A\lambda_d - A\lambda_u \frac{rA^{1/2}}{2\bar{v}} \frac{\varepsilon}{2}$$

$$b = \frac{1}{\sqrt{\lambda_d - \lambda_u \frac{rA^{1/2}}{2\bar{v}} \frac{\varepsilon}{2}}} \qquad T_a = \frac{1}{2\overline{v_u}\sqrt{\lambda_d - \lambda_u \frac{rA^{1/2}}{2\bar{v}} \frac{\varepsilon}{2}}}$$

Physical interpretation of results

$$Z_u = \lambda_u \cdot A \cdot \left[\left(\alpha_A \cdot \frac{1}{2\overline{v_u}\sqrt{\lambda_d - \lambda_u \frac{rA^{1/2}}{2\bar{v}} \frac{\varepsilon}{2}}} + \alpha_W \cdot 0 + \alpha_{IV} \cdot \frac{rA^{1/2}}{2\bar{v}} \right) + \frac{D + \frac{rA^{1/2}}{2} \cdot \tau_{km}}{VoT_u} \right]$$

$$Z_d = \frac{\lambda_d A}{VoT_d} \left[-\frac{\lambda_u}{\lambda_d} \cdot (D + \frac{rA^{1/2}}{2} \cdot \tau_{km}) + \frac{\lambda_u}{\lambda_d} \cdot \frac{rA^{1/2}}{2\bar{v}} \varepsilon/2 \cdot C_{km} + C_h \right]$$

$$\frac{\partial Z_u}{\partial \lambda_d} = -\frac{\lambda_u \cdot A \cdot \alpha_{A\cdot}}{4\overline{v_u}\sqrt{\left(\lambda_d - \lambda_u \frac{rA^{1/2}}{2\bar{v}} \frac{\varepsilon}{2}\right)^3}}$$

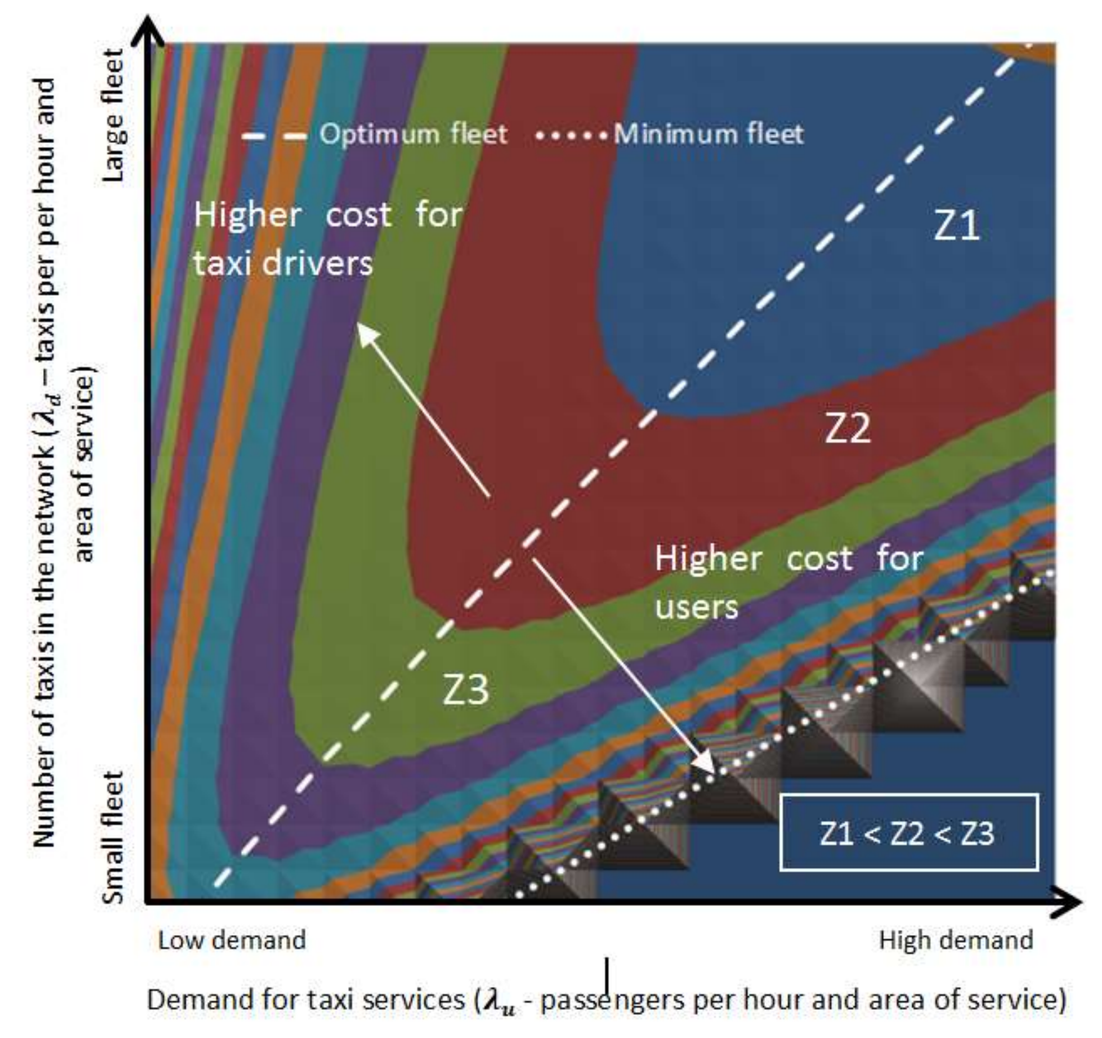
$$\frac{\partial Z_d}{\partial \lambda_d} = \frac{A \cdot C_h}{VoT_d}$$

$$A \cdot C_h = \frac{\lambda_u \cdot A \cdot \alpha_{A\cdot} \cdot VoT_d}{4\overline{v_u}\sqrt{\left(\lambda_d - \lambda_u \frac{rA^{1/2}}{2\bar{v}} \frac{\varepsilon}{2}\right)^3}}$$

$$\boldsymbol{\lambda_d = \lambda_u \frac{rA^{1/2}}{2\bar{v}} \frac{\varepsilon}{2} + \left(\frac{\lambda_u \alpha_A VoT_d}{4\overline{v_u} C_h} \right)^{2/3}}$$

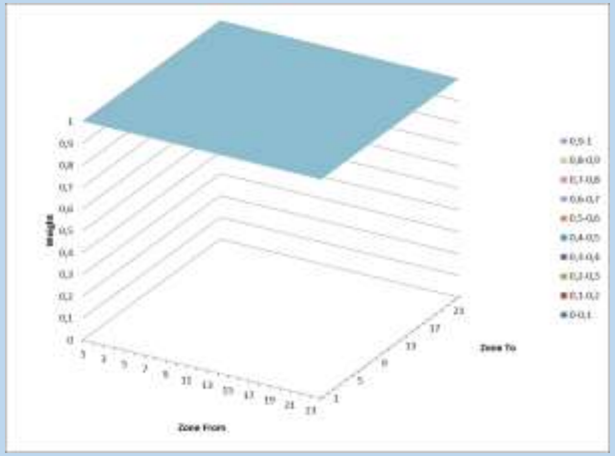
Minimum fleet   Extra fleet

Plot the results (visualize)

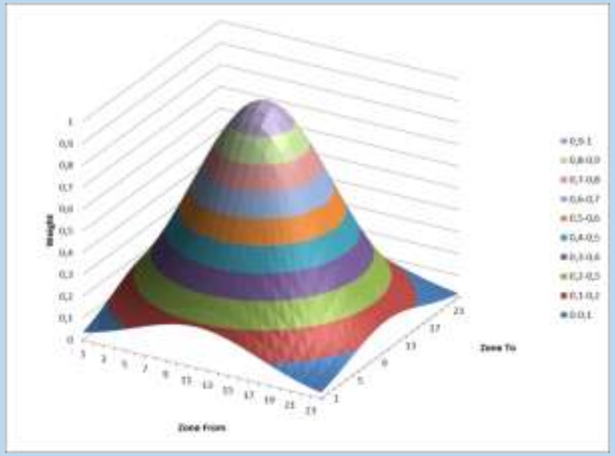


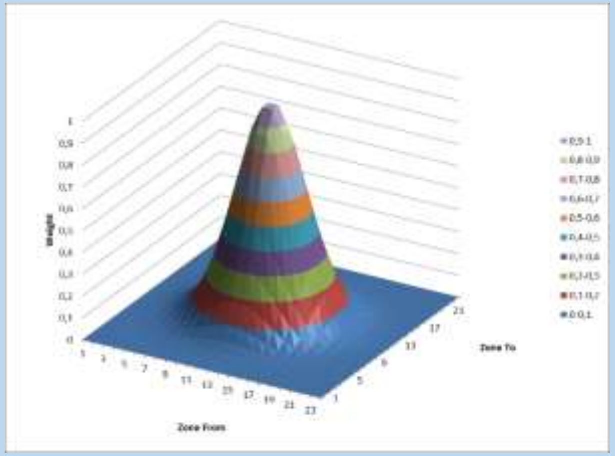
Control the “error”

Uniform demand

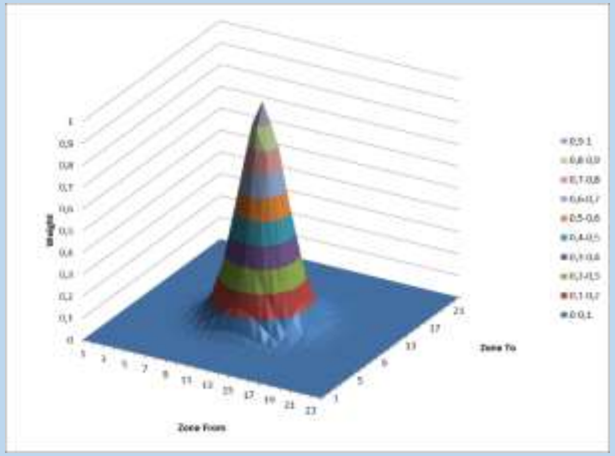


Non-uniform demand





Non-uniform demand

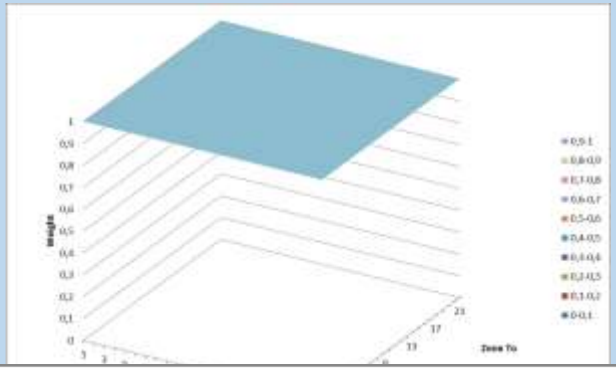


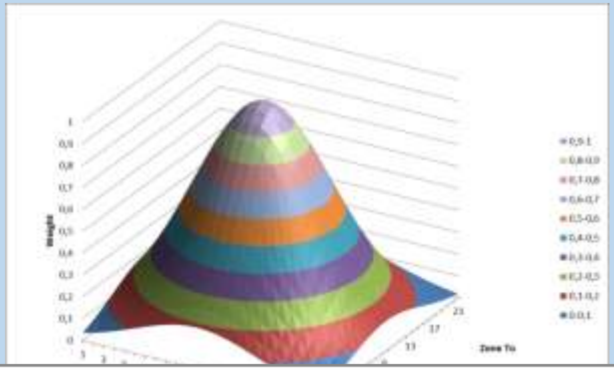
Non-uniform demand

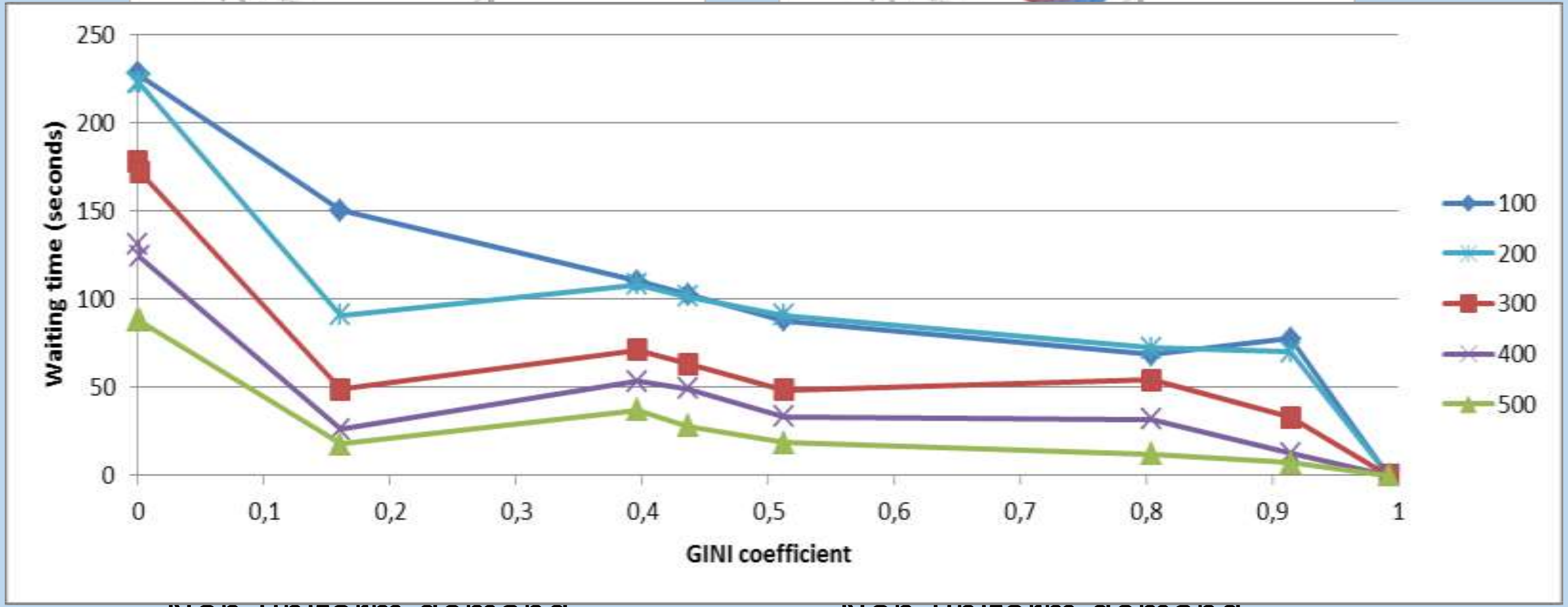
Control the “error”

Uniform demand

Non-uniform demand







Non-uniform demand

Non-uniform demand

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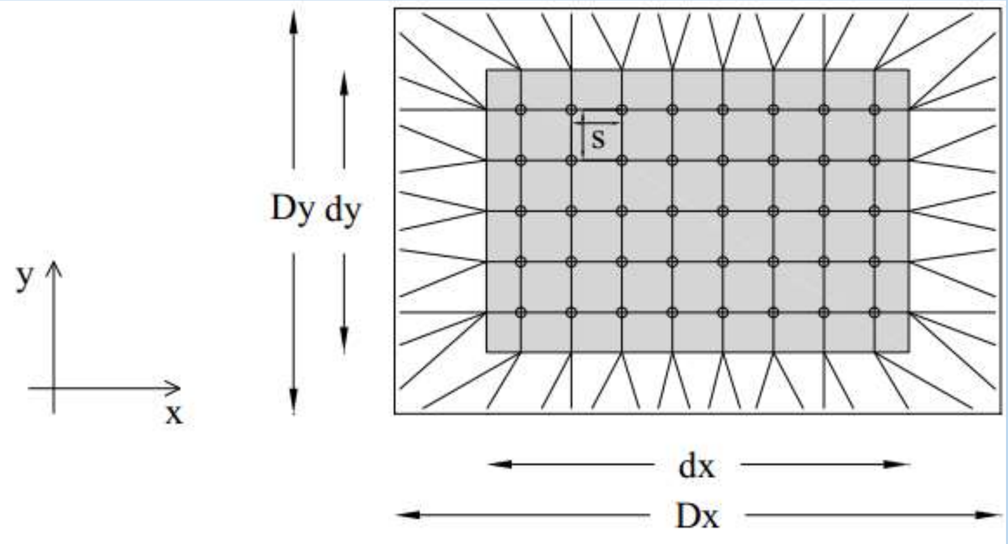
Bus Rapid Transit στην Βαρκελώνη

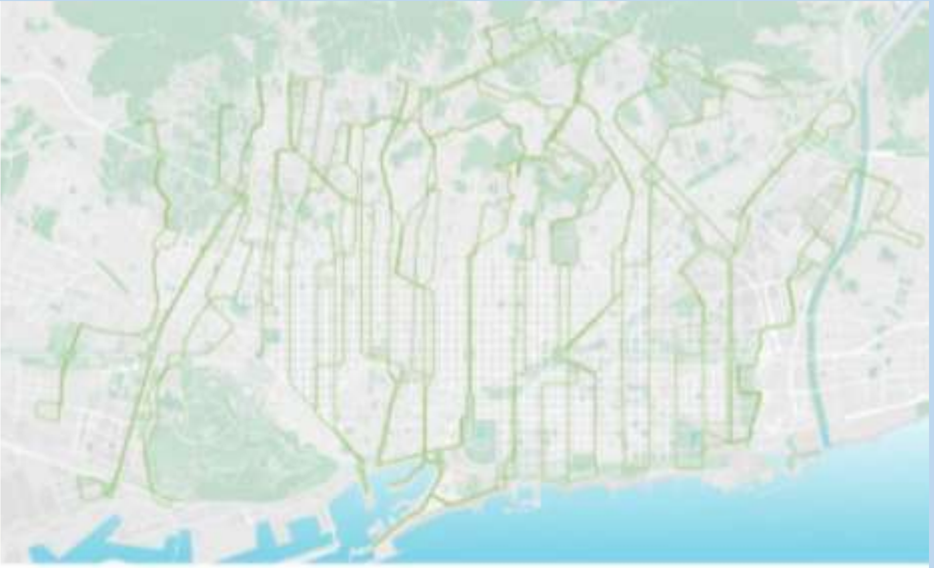


$$FO_1 = Z_T = Z_o + Z_u + Z_{vp} =$$
$$= (\pi_L \cdot L + \pi_V \cdot V + \pi_M \cdot M) + (T_a + T_w + T_t + T_r) + (T_a^{vp} + T_r^{vp})$$

Jordi Amat Altes
Miquel Angel Estrada Romeu

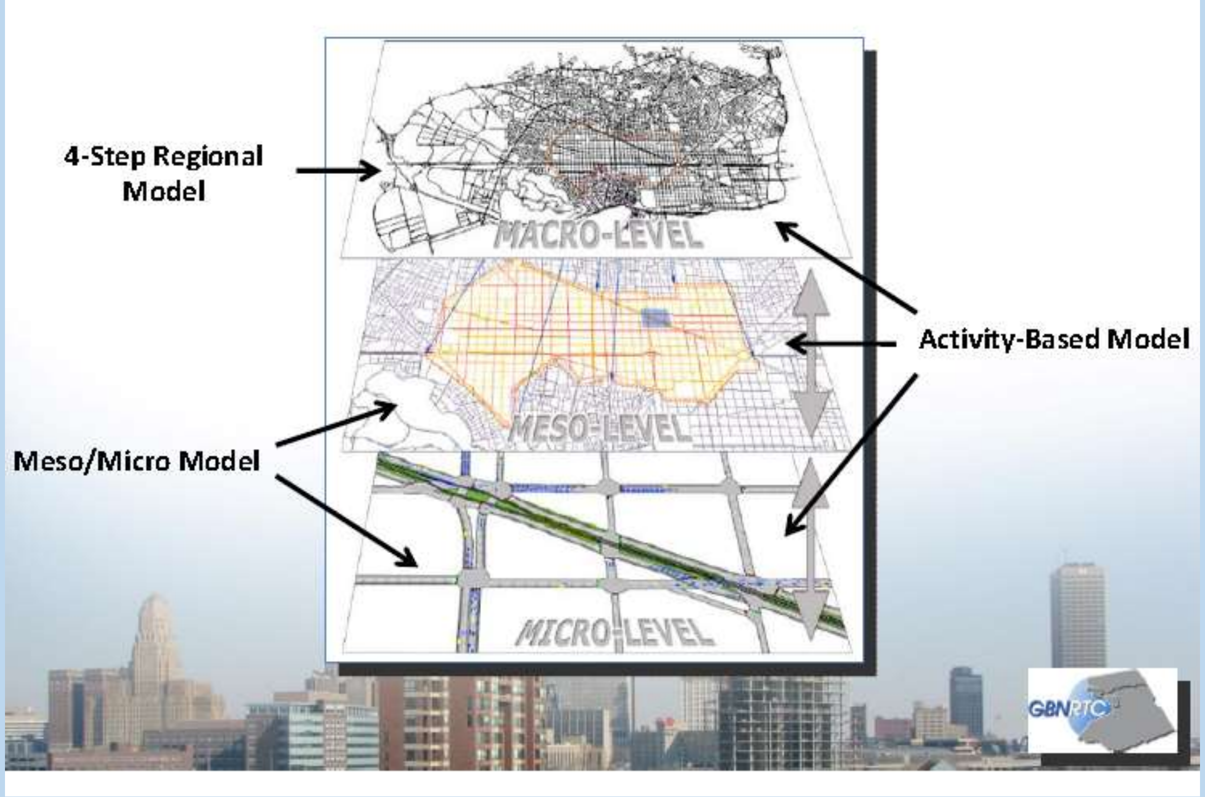
UPC Escola Tècnica Superior d'Enginyers de Camins, Canals i Ports de Barcelona
UNIVERSITAT POLITÈCNICA DE CATALUNYA

Nombre esperat de transfers	$E(e_T) = \frac{1}{2}\left(3 + \alpha_x^2 + \alpha_y^2 + \alpha_x^2\alpha_y^2 - 4\alpha_x\alpha_y\right) - \frac{s}{2D_x}\left(2 + 2\alpha_x - 3\alpha_y - \alpha_x\alpha_y + \alpha_y^2 + \alpha_x\alpha_y^2\right) - \frac{s}{2D_y}\left(2 + 2\alpha_y - 3\alpha_x - \alpha_x\alpha_y + \alpha_x^2 + \alpha_y\alpha_x^2\right) + \frac{s^2\alpha_x\alpha_y}{D_x D_y}$
Longitud de xarxa	$L = \frac{D_x D_y}{s}\left(1 + \alpha_x\alpha_y\right)$
Vehicles – kilòmetre per hora	$V = \frac{2D_x D_y}{sH}\left[\alpha_x + \alpha_y + \alpha_x(1-\alpha_x)\frac{D_x}{2D_y} + \alpha_y(1-\alpha_y)\frac{D_y}{2D_x}\right]$
Vehicles – hora per hora	$M = \frac{V}{v_c}$ amb $\frac{1}{v_c} = \left(\frac{1}{v} + \frac{\tau}{s} + \gamma\tau'\right)$ amb $\gamma = \frac{\Lambda(1+e_T)}{V}$
Ocupació màxima	$O_b = \max\left\{\frac{\Lambda Hs(1+\alpha_y)(1-\alpha_x)}{2\alpha_y D_y}; \frac{\Lambda H(1+\alpha_x)^2(1-\alpha_y)^2}{32} + \frac{\Lambda Hs}{8\alpha_y D_y}\left(4 - (1+\alpha_x)^2(1-\alpha_y)^2 - 2\alpha_x^2\alpha_y^2\right)\right\} \le C$
Temps d'accés	$A = \frac{2d}{v_w} = \frac{s}{v_w}$
Temps d'espera	$W = \frac{H}{3\alpha_x}(1-\alpha_x^3)\frac{(1-\alpha_y)}{(1-\alpha_x)} + \frac{H}{3\alpha_y}(1-\alpha_y^3)\frac{(1-\alpha_x)}{(1-\alpha_y)} + \frac{H}{4}(1 + \alpha_x^2 + \alpha_y^2 + \alpha_x^2\alpha_y^2) - \frac{Hs}{4D_x}(1-\alpha_y)^2(1+\alpha_x) - \frac{Hs}{4D_y}(1-\alpha_x)^2(1+\alpha_y)$
E(E)	$E(E) = \left(\frac{\alpha_y^2 D_y^2 + \alpha_x^2 D_x^2 + 4\alpha_x\alpha_y D_x D_y}{4(\alpha_x D_x + \alpha_y D_y)} + \frac{(\alpha_x D_x + \alpha_y D_y)}{12\alpha_x\alpha_y D_x D_y}\left(1 - \frac{\alpha_x\alpha_y}{2}\right)\right)(1 - \alpha_x^2\alpha_y^2) + \frac{1}{3}(\alpha_x D_x + \alpha_y D_y)(\alpha_x^2\alpha_y^2) + \frac{1}{4}\left(D_x(2 - 3\alpha_x + \alpha_x^3) + D_y(2 - 3\alpha_y + \alpha_y^3)\right)$



Transport models

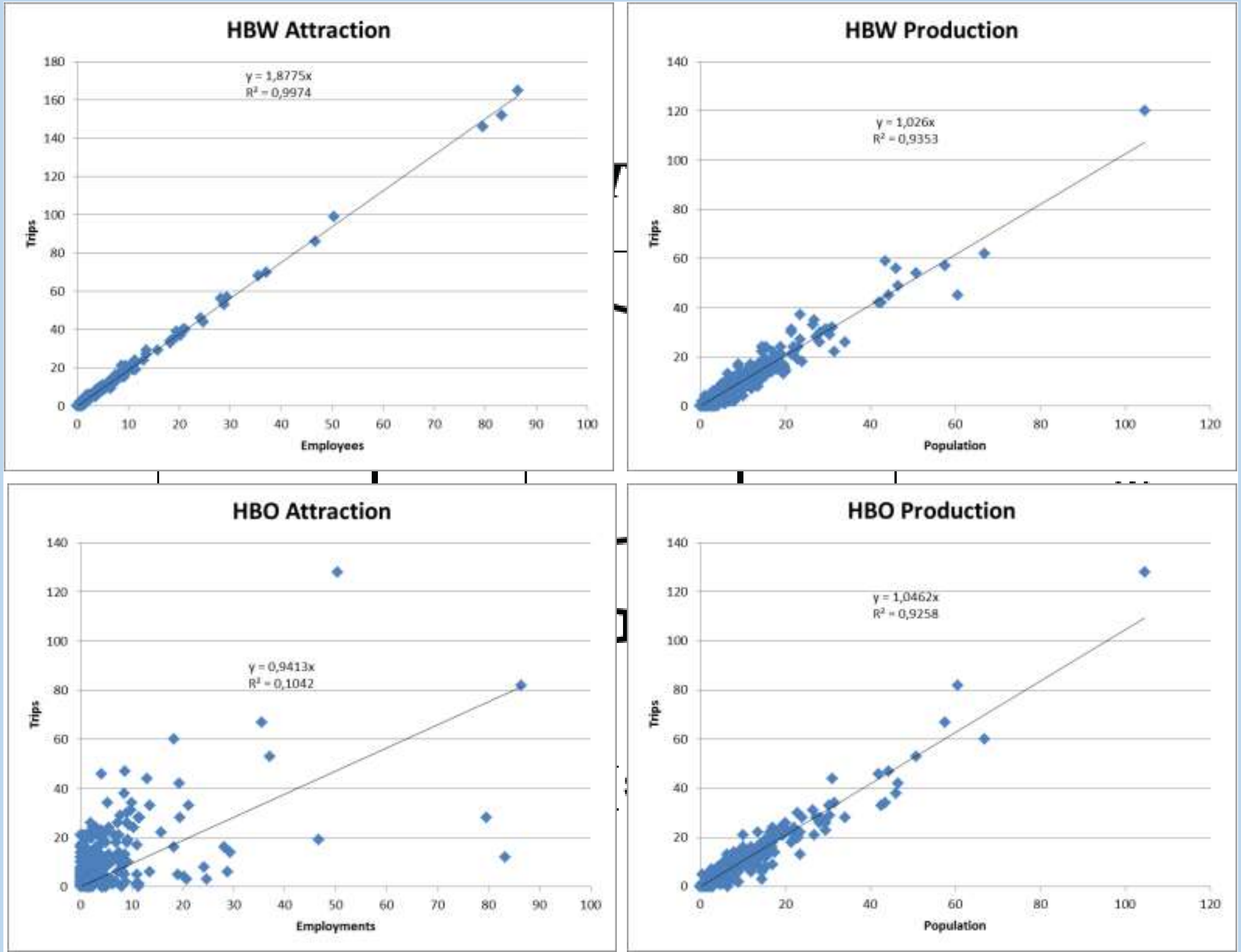
- *Temporal resolution: static / pseudo-static / dynamic*
- *Spatial resolution: macro / meso / micro / agent*
- *Trip versus trip chain versus activity*



4 steps model

- **Generation**
  - Land uses - population
  - Socieconomical characteristics
- **Distribution**
  - Production-Attraction models
  - Home based vs non home based
  - Gravity / entropy models
- **Modal Split**
  - Stated preference: Revealed - Declared
  - Generalized cost – utility function
  - Logit-probit models – S curves
- **Assignment**
  - Equilibrium (Wardrop)
  - Shortest path (Dijkstra)
  - Volume delay function (BPR, impedance, friction curves)

4 steps model



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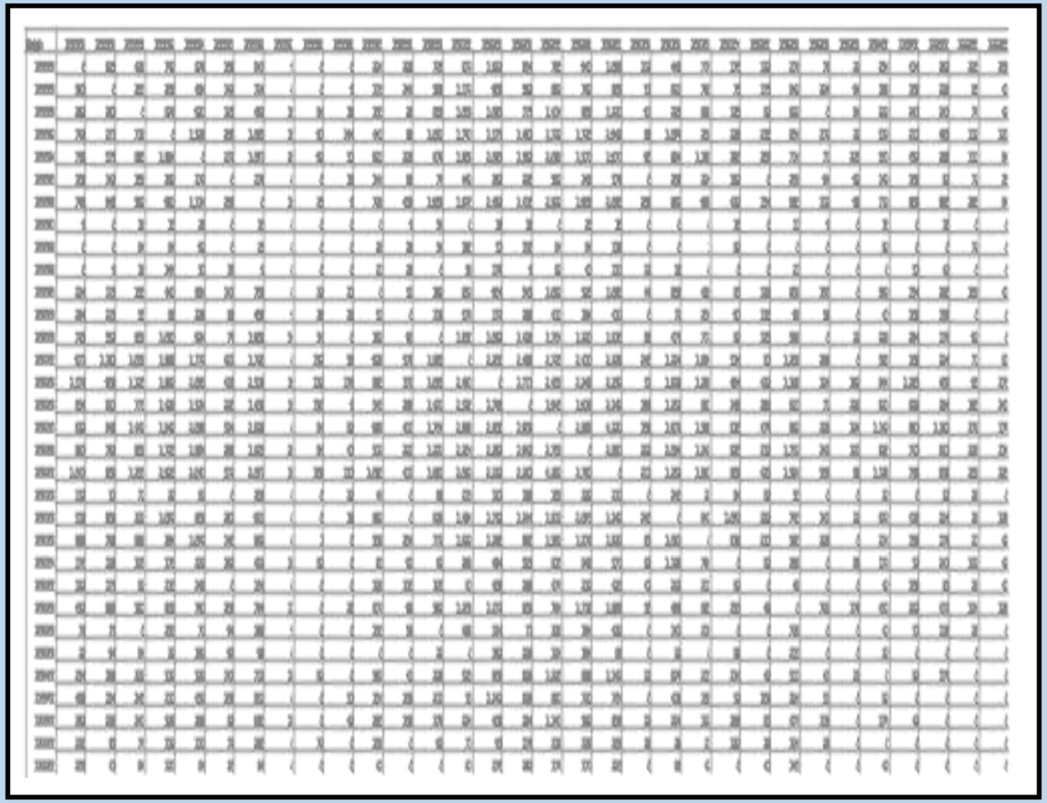
4 steps model



PRODUCTION

ATTRACTION

4 steps model

Typical approach: econometric individual discrete choice model prescribed by Daniel McFadden that relies on a logit type model.

$$P_T = \frac{e^{U_T}}{e^{U_A} + e^{U_T}}$$

$$U_T = 1.1636 + 0.0916\, X_{DX} + 0.0563\, X_{DT} + 0.0106\, X_{DC}$$

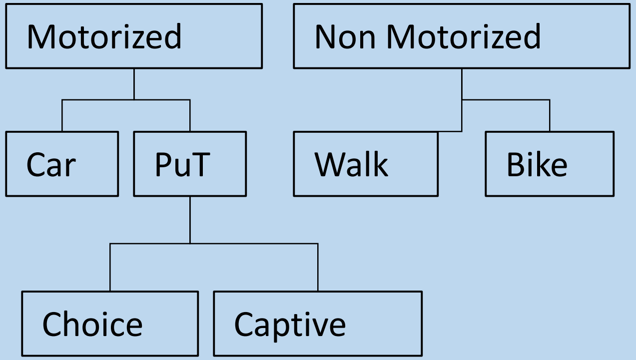
$$U_A = -1.4809 + 1.95\, X_I$$

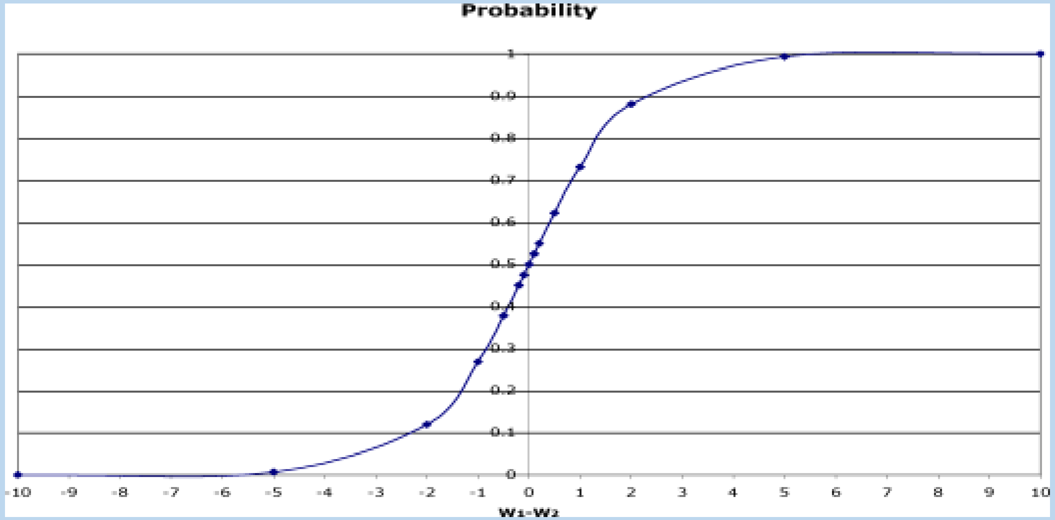
X_I is the adjusted **income** of the users

X_{DX} is the difference in **access time**

X_{DT} is the difference in inline **travel time**

X_{DC} is the **cost** difference



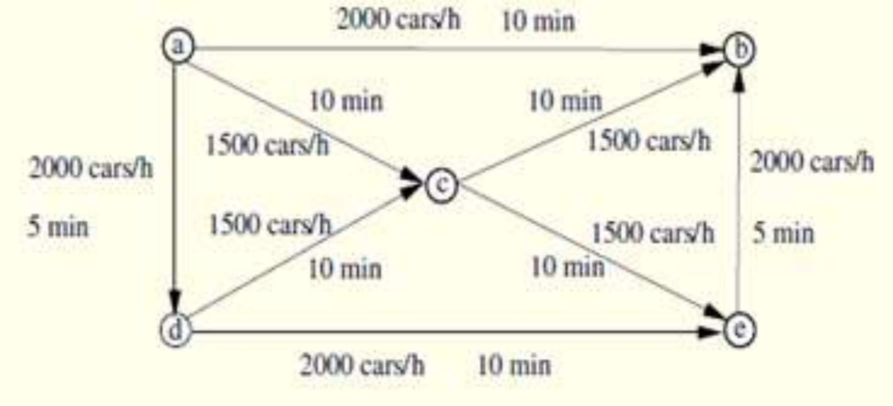


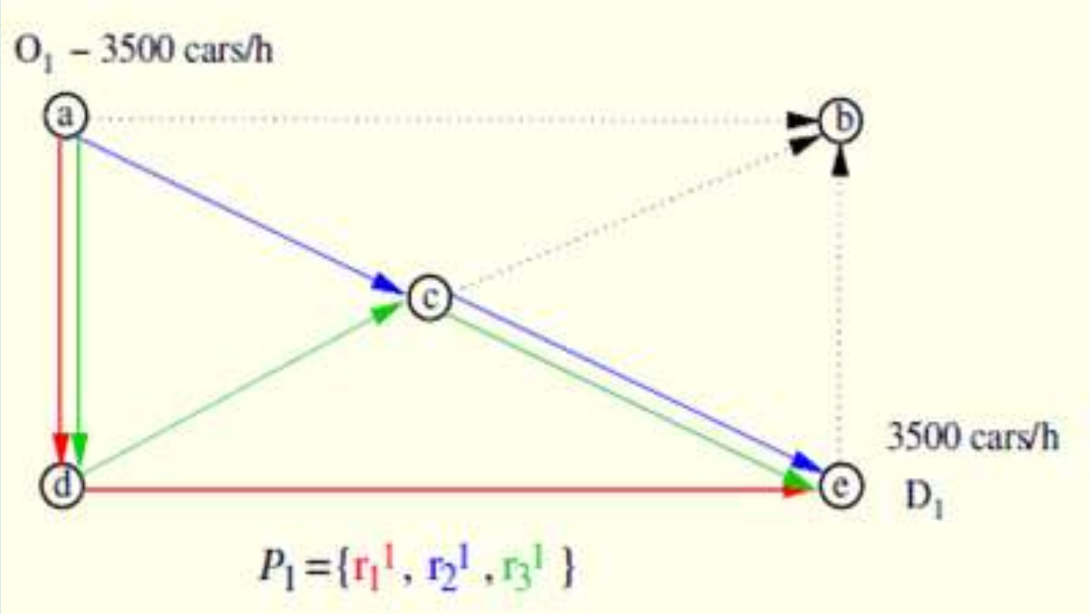
4 steps model

Demand

	A	B	C	D	E
A	0				3500
B		0			
C			0		
D				0	
E	3500?				0

Supply

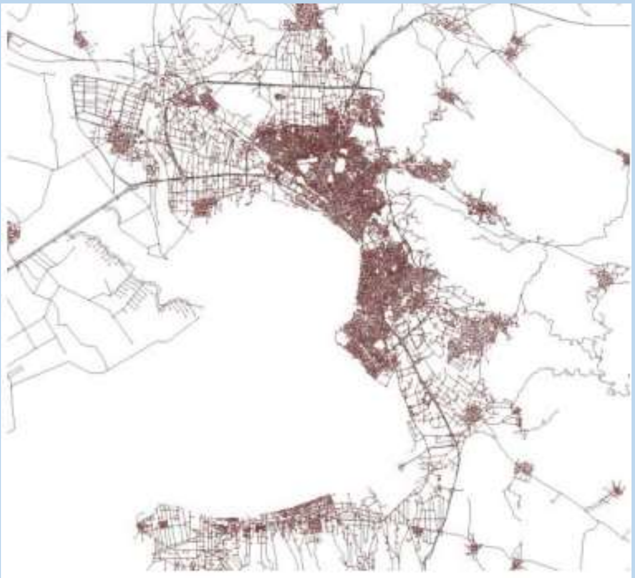


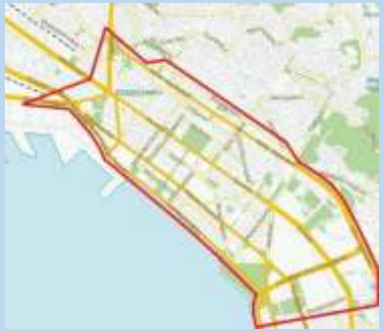


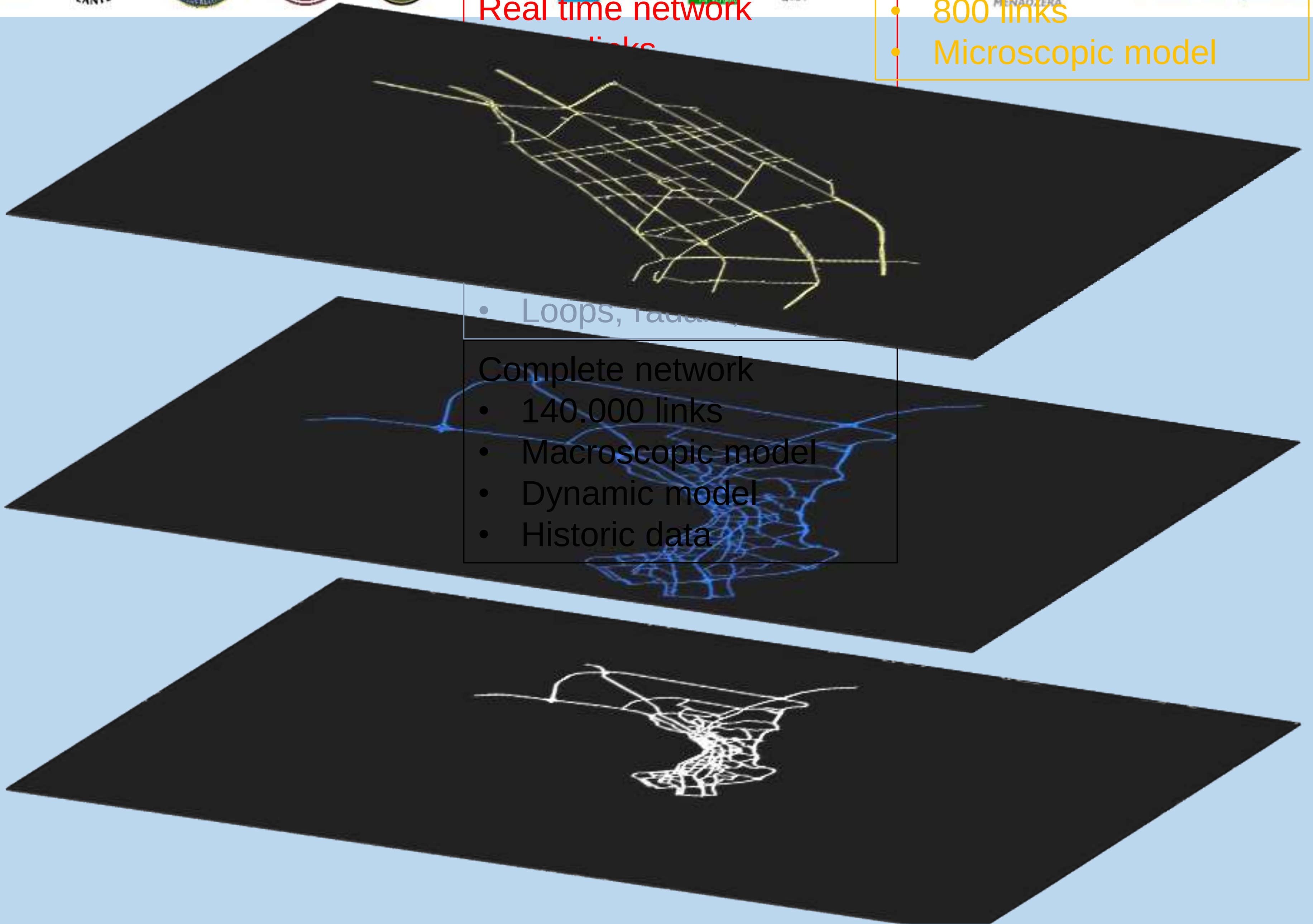
Equilibrium (Wardrop)
Shortest path (Dijkstra)
Volume delay function (BPR)

CERTH-HIT models

- Software and know-how
  - Aimsun advanced edition (micro) [A]
  - SUMO [S]
  - VISUM (full), VISSIM [V, v]
  - Matlab (agent-based) [M]





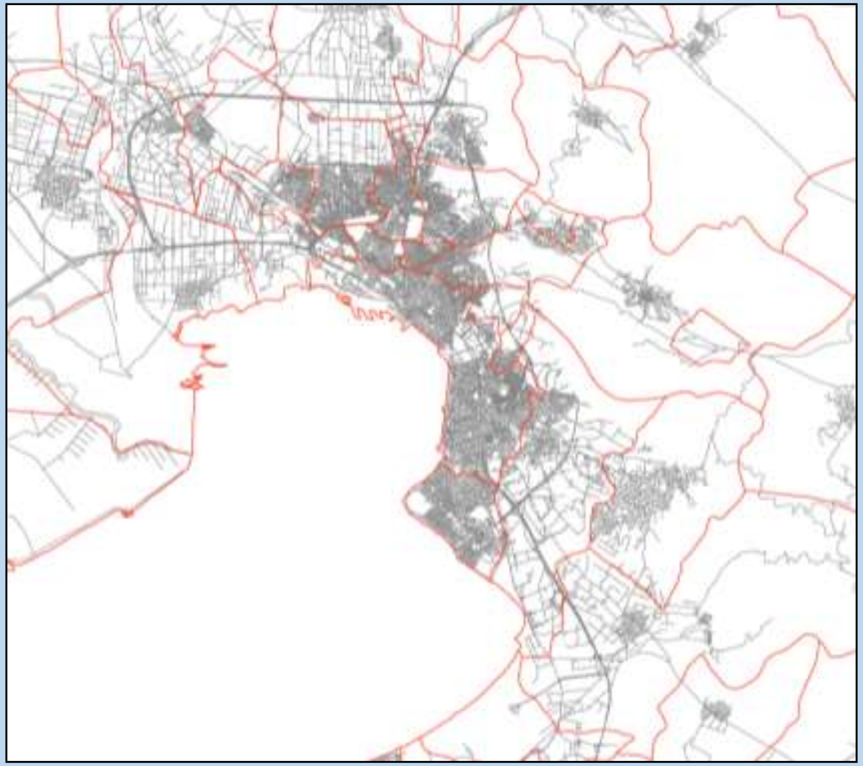


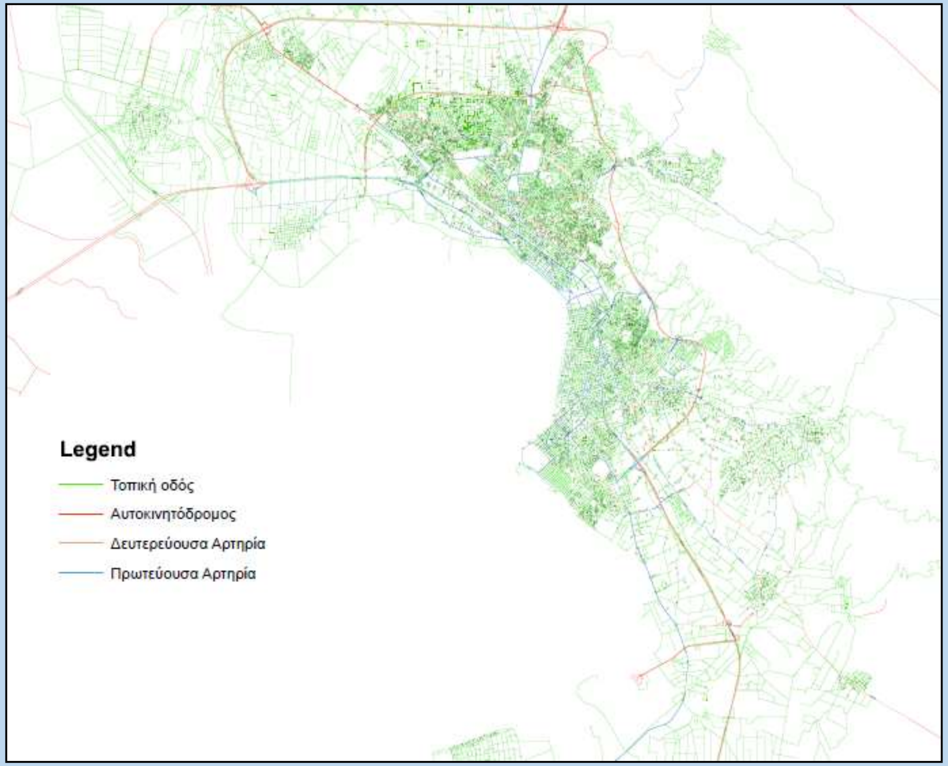
Cooperative network
- 800 links
- Microscopic model

Real time network
- links
- Loops, ra

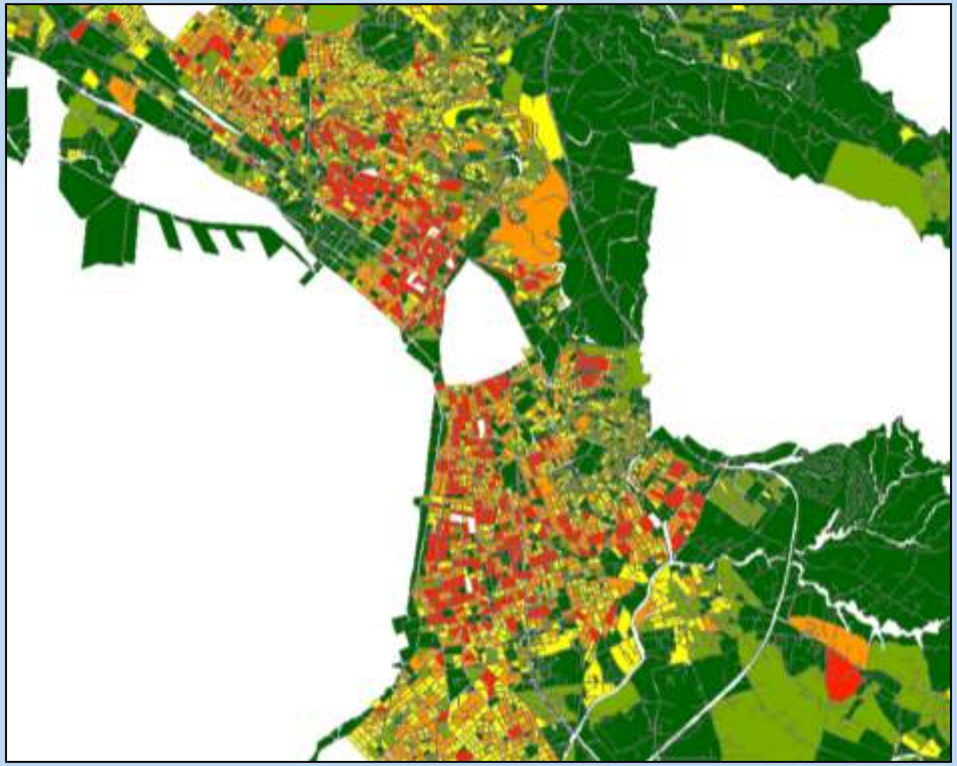
Complete network
- 140.000 links
- Macroscopic model
- Dynamic model
- Historic data

Macro-scopic strategic model

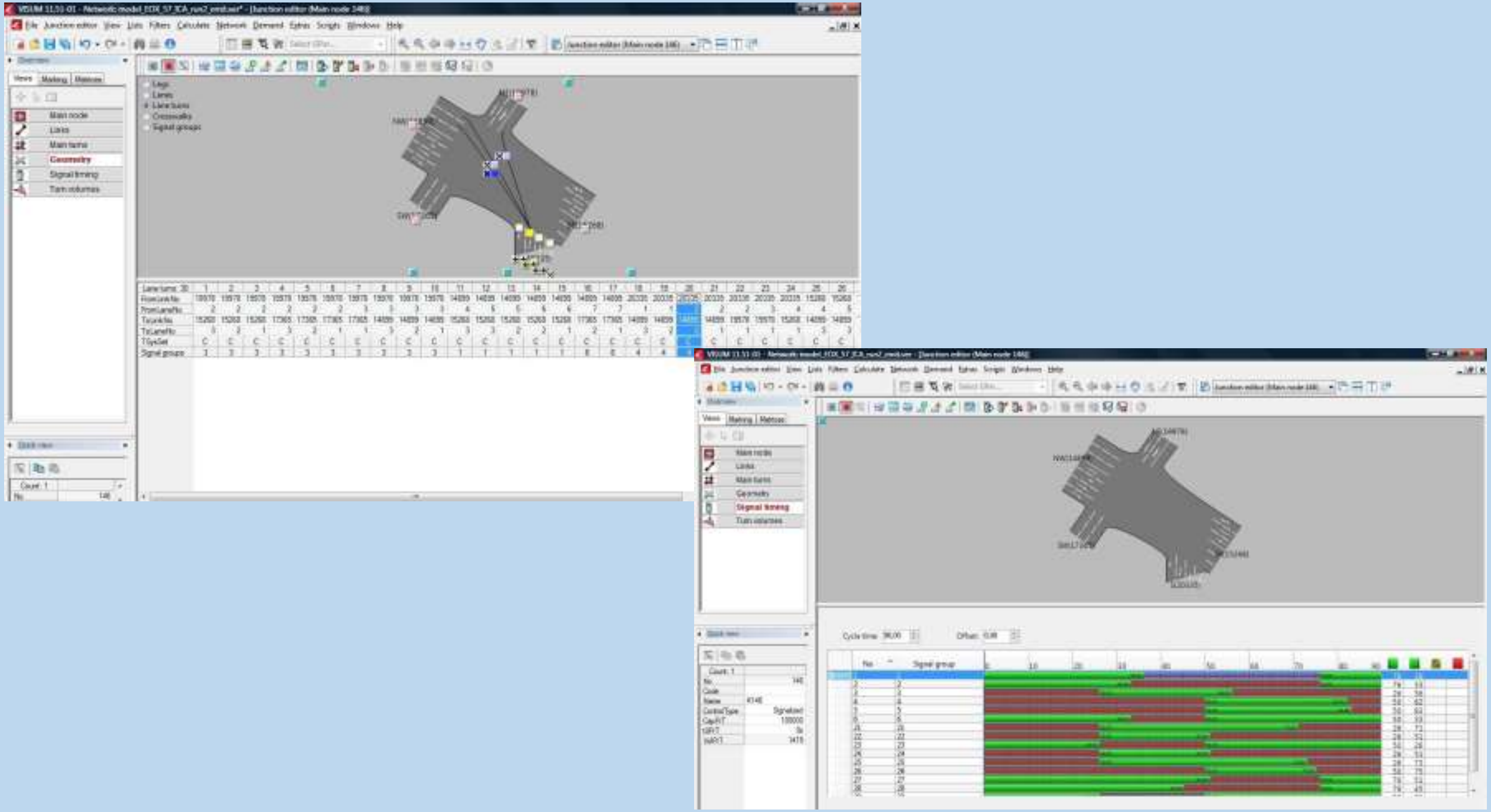




Macro-scopic strategic model

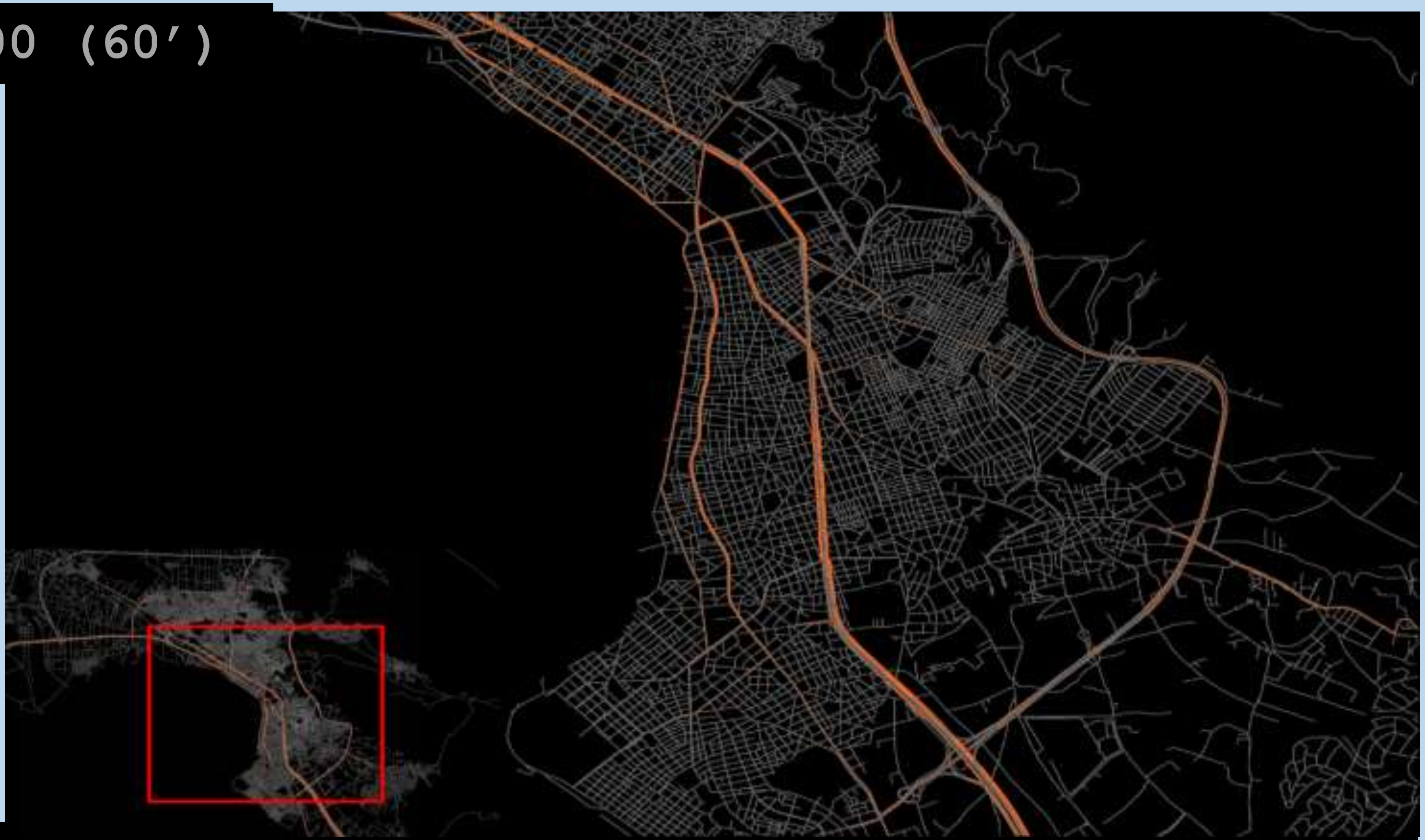


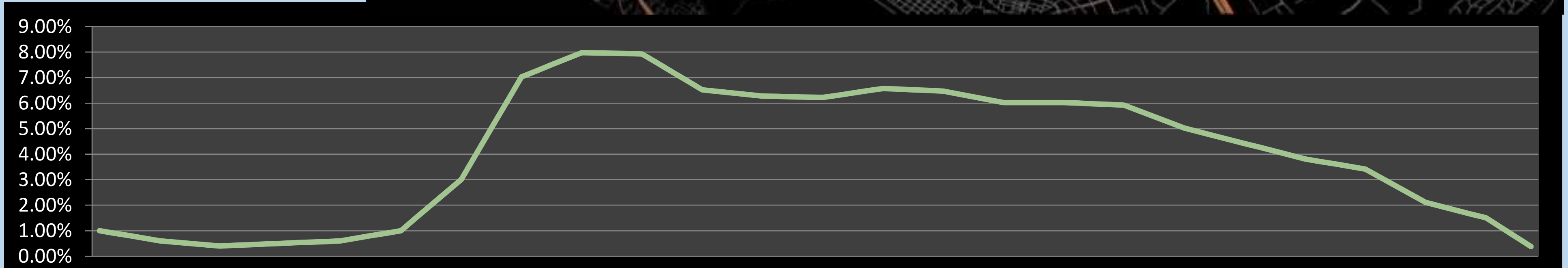
Macro-scopic strategic model



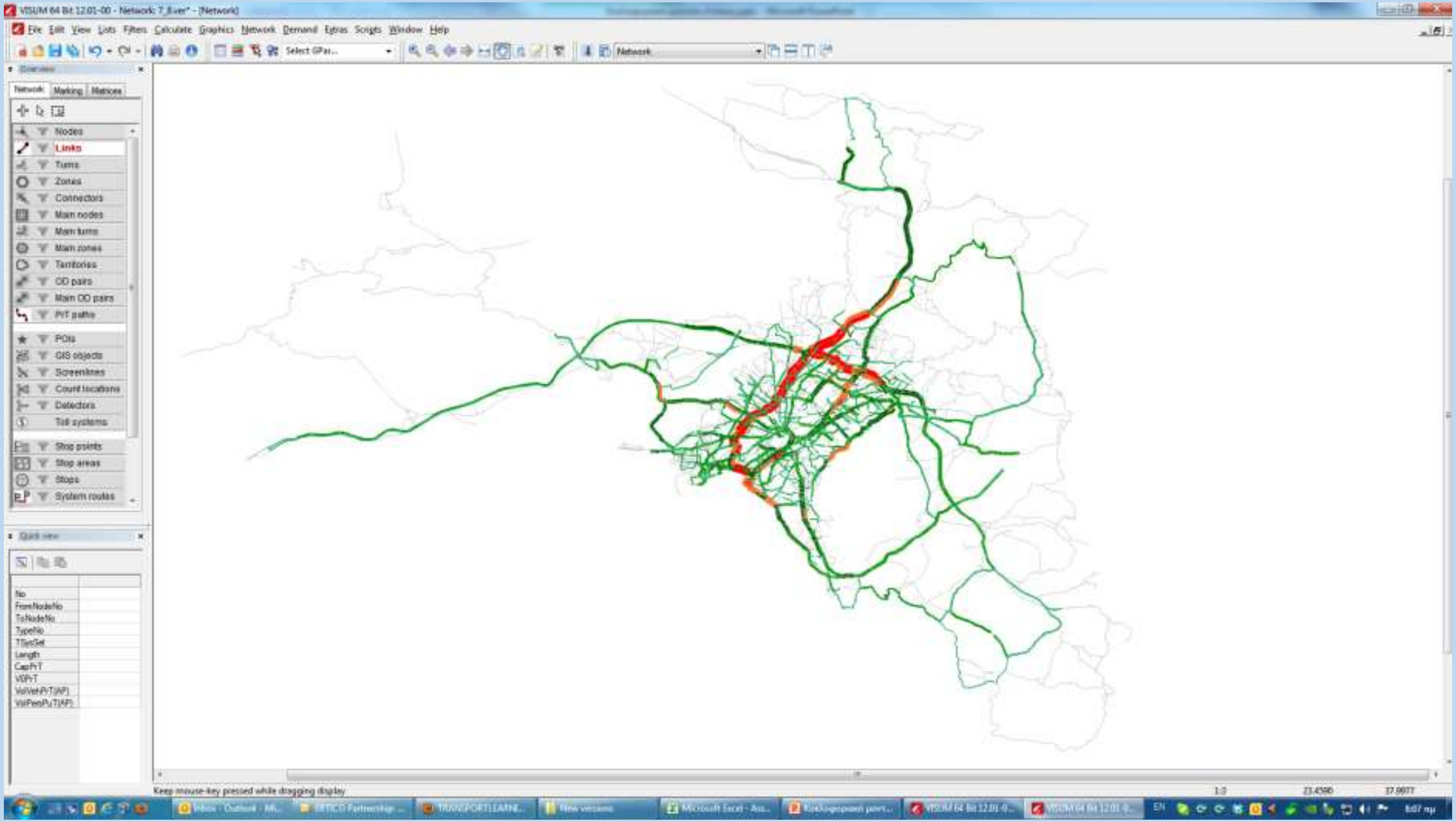
Δυναμικές κυκλοφοριακές ροές

23:00 – 24:00 (60′)

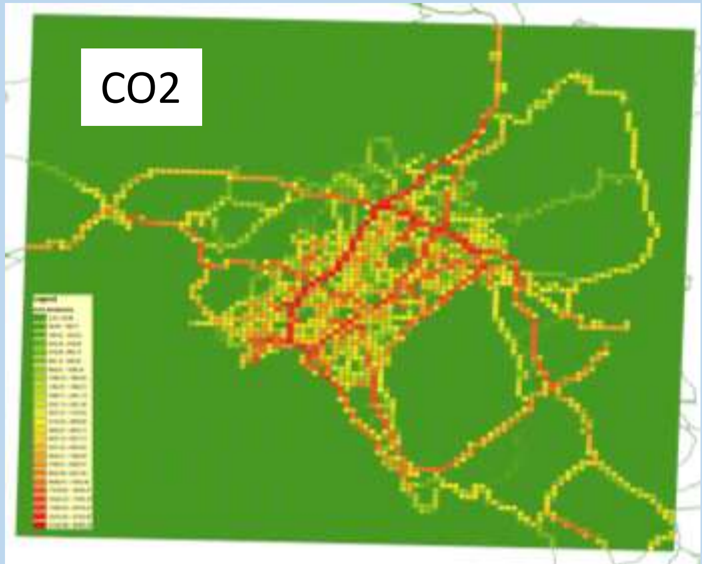


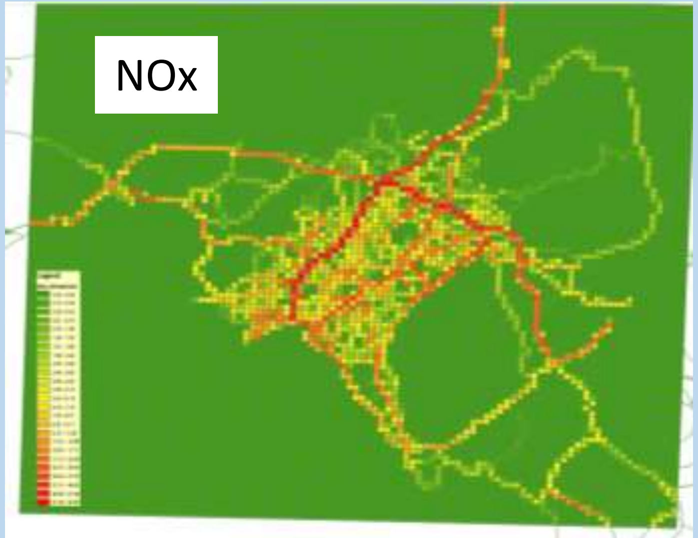


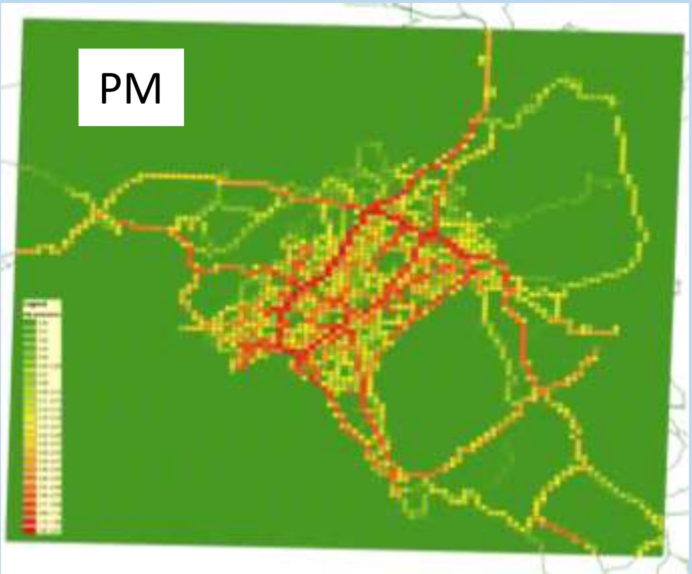
Macro-scopic strategic model

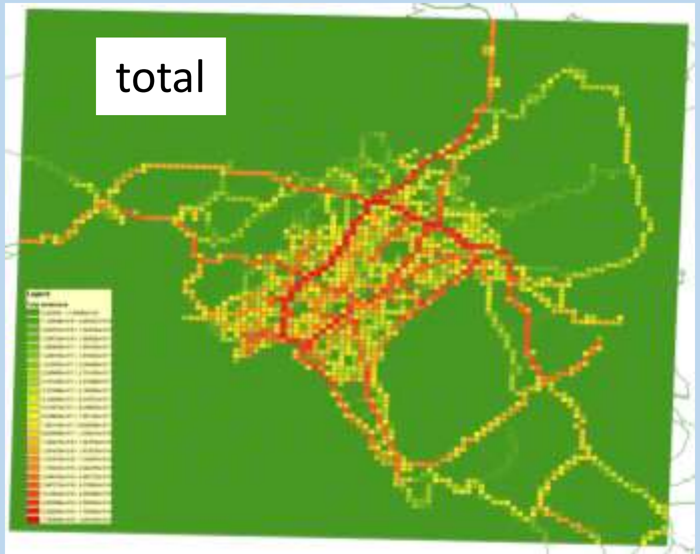


Macro-scopic strategic model



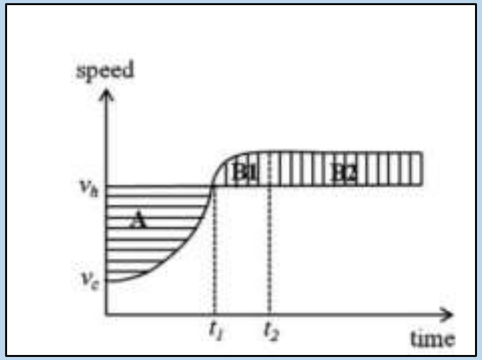






Micro-scopic model for C-ITS

Service logic

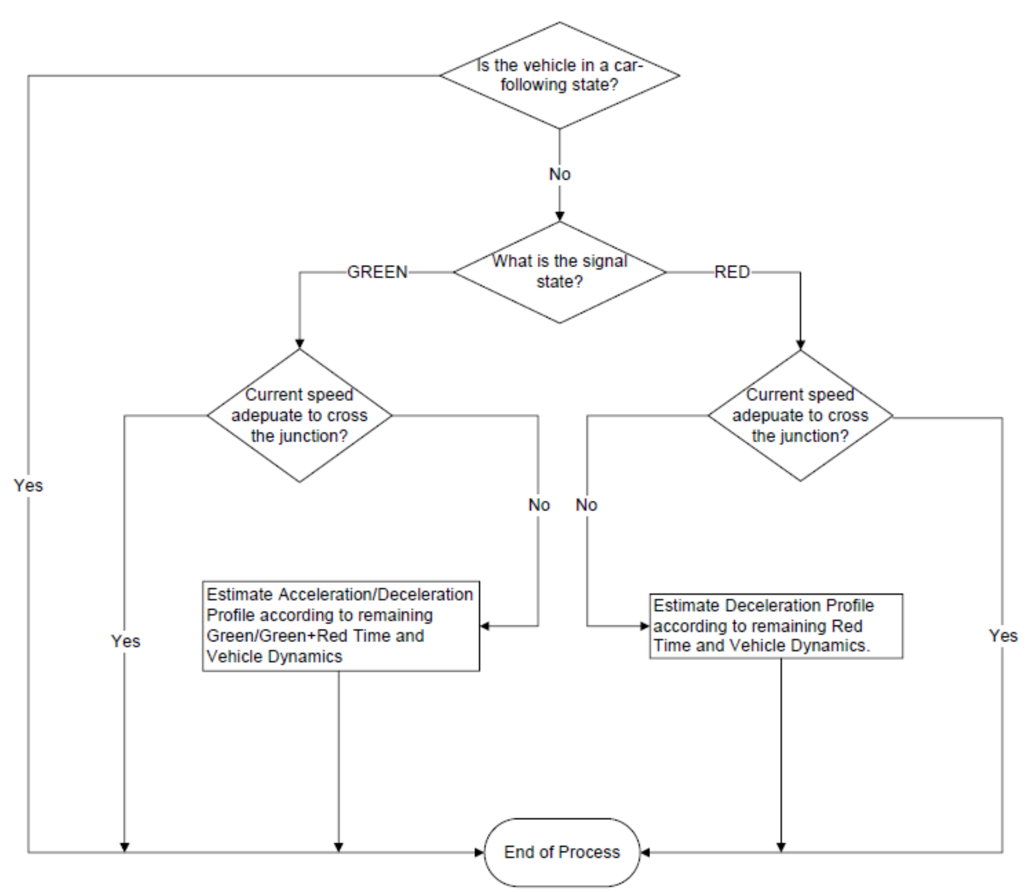


$$v_h - v_d \cos(mt), \qquad t \in \left[0, t_1 = \frac{\pi}{2m}\right)$$

$$v_h - v_d \frac{m}{n} \cos\left(n\left(t - \frac{\pi}{2m} + \frac{\pi}{2n}\right)\right), \qquad t \in \left[t_1 = \frac{\pi}{2m}, t_2 = \left(\frac{\pi}{2n} + \frac{\pi}{2m}\right)\right)$$

$$v_h - v_d \frac{m}{n}, \qquad t \in \left[t_2 = \left(\frac{\pi}{2n}, \frac{\pi}{2m}\right), \frac{d_0}{v_h}\right]$$

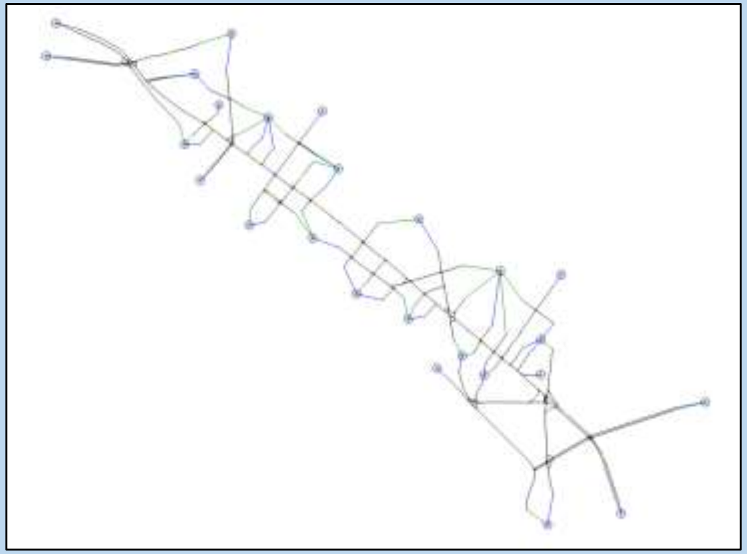
$$v_d = v_h - v_c$$



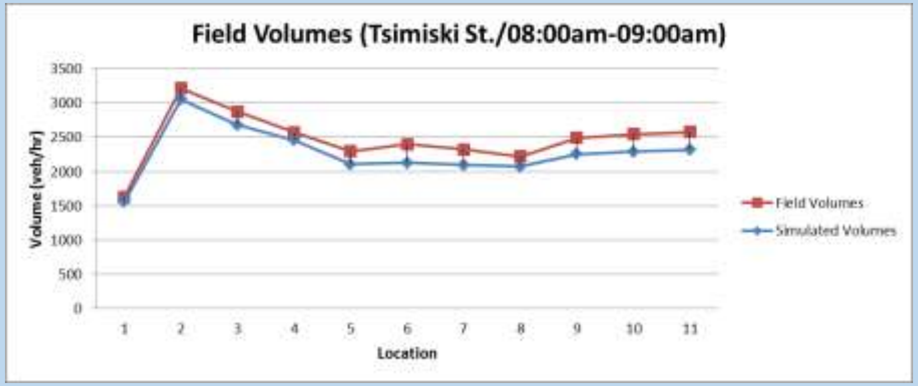
M. Barth, S. Mandava, K. Boriboonsomsin, H. Xia, "Dynamic ECO-Driving for Arterial Corridors", 2011 IEEE Forum on Integrated and Sustainable Transportation Systems, Vienna, Austria, June 29 – July 1, 2011.

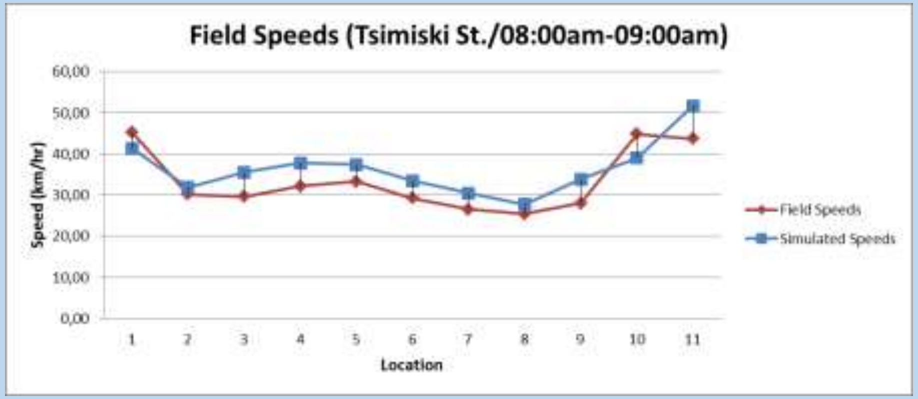
Microscopic traffic model

Aimsun microscopic traffic simulator

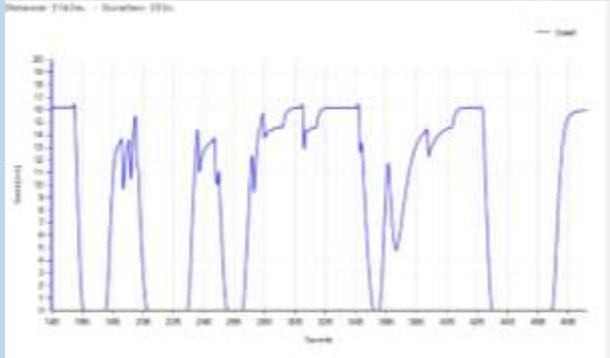


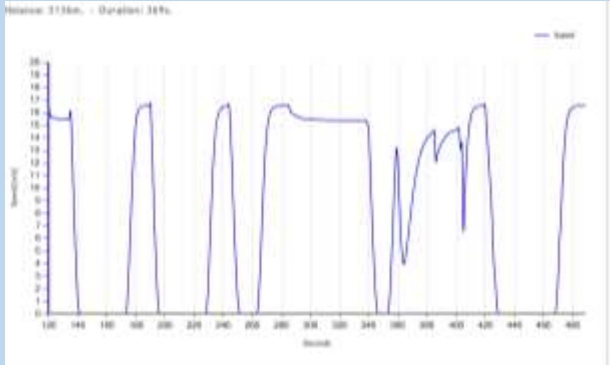
Aimsun (Transport Simulations Systems). *http://www.aimsun.com/wp/*

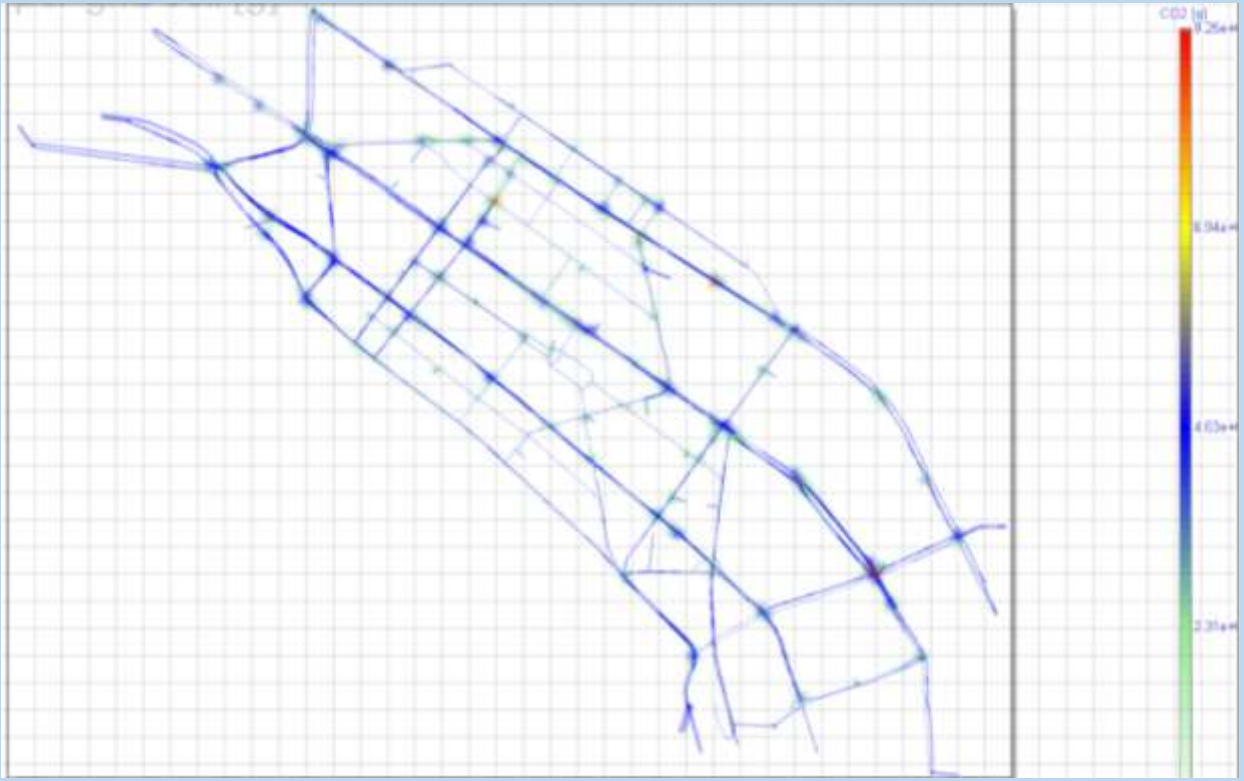




Micro-scopic model for C-ITS







Evaluation of results - harmonization

Large variability of results

12%-13% 20% 28% 47% Energy savings

0 % 100 %

12%-14% 56% Reduced emissions

0%

100%

Mandava S., Boriboonsomsin K., Barth M. (2009) - light traffic conditions
Li M., Boriboonsomsin K., Wu G., Zhang W.B., Barth M. (2009) - two consequent signalized intersections
Barth M., Mandava S., Boriboonsomsin K., Xia H. (2011) - signalized arterial
Xia H., Boriboonsomsin K., Barth M. (2013) - medium demand and low user penetration rates
Barth M., Boriboonsomsin K. (2009) - real world experimental run

Vreeswijk J.D., Mahmod M.K.M., van Arem B. (2010) - adaptive balancing and control system

Schuricht P., Michler O., Bäker B. (2011) - very low traffic conditions

Asadi B, Vahidi A. (2011) - integration of dynamic eco-driving into adaptive cruise control

Evaluation of results - harmonization

Need for evaluation “standards”

- Road type (arterial, urban, interurban)
- Geographic influence (urban area, route)
- “Network” characteristics (spacing, cycle time)
- Congestion (high, medium, low, very low)
- Penetration (infrastructure and vehicle)
- Service(s) logic (“hand made”)
- Simulation algorithm (traffic + fuel/emissions)

THANK YOU!