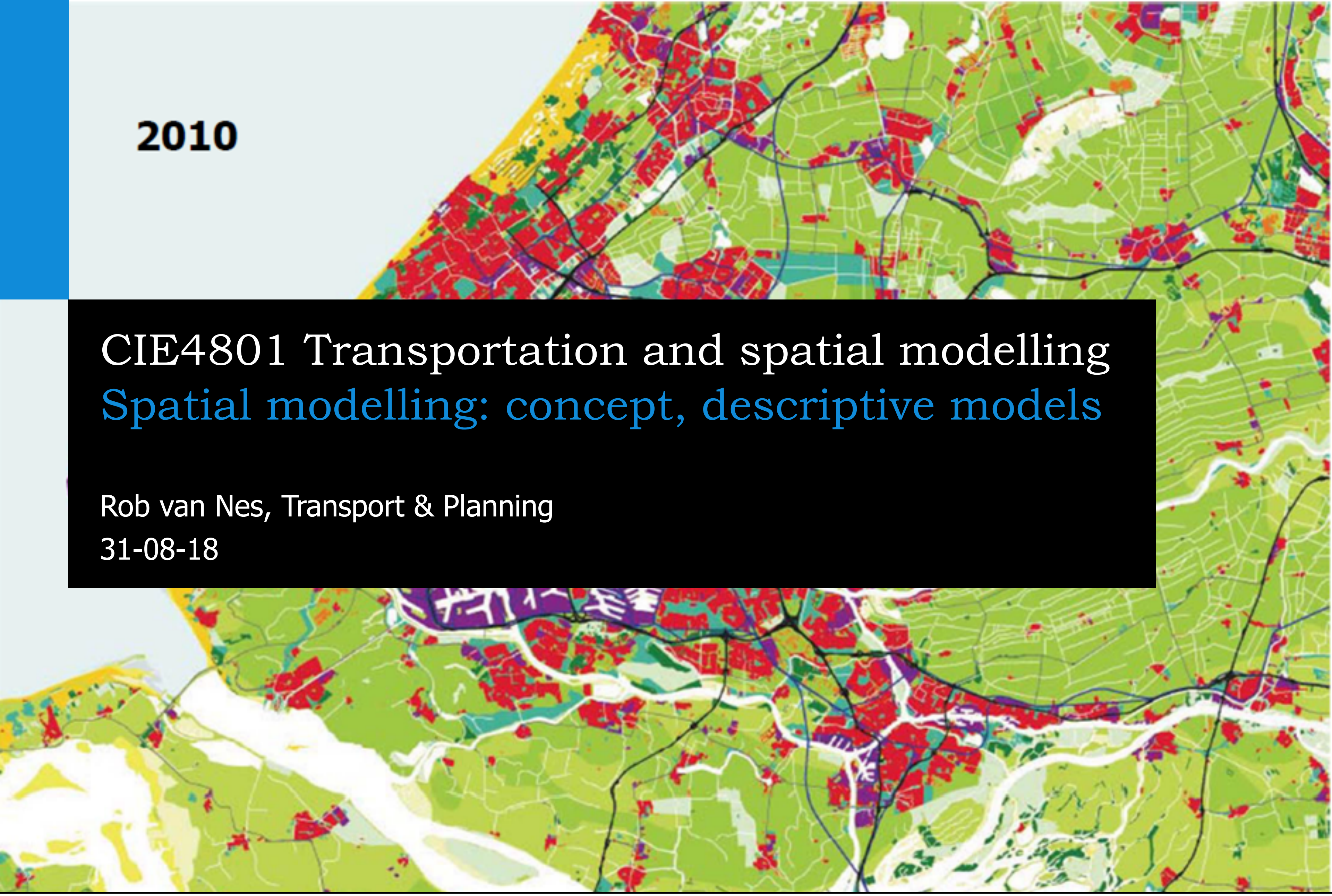


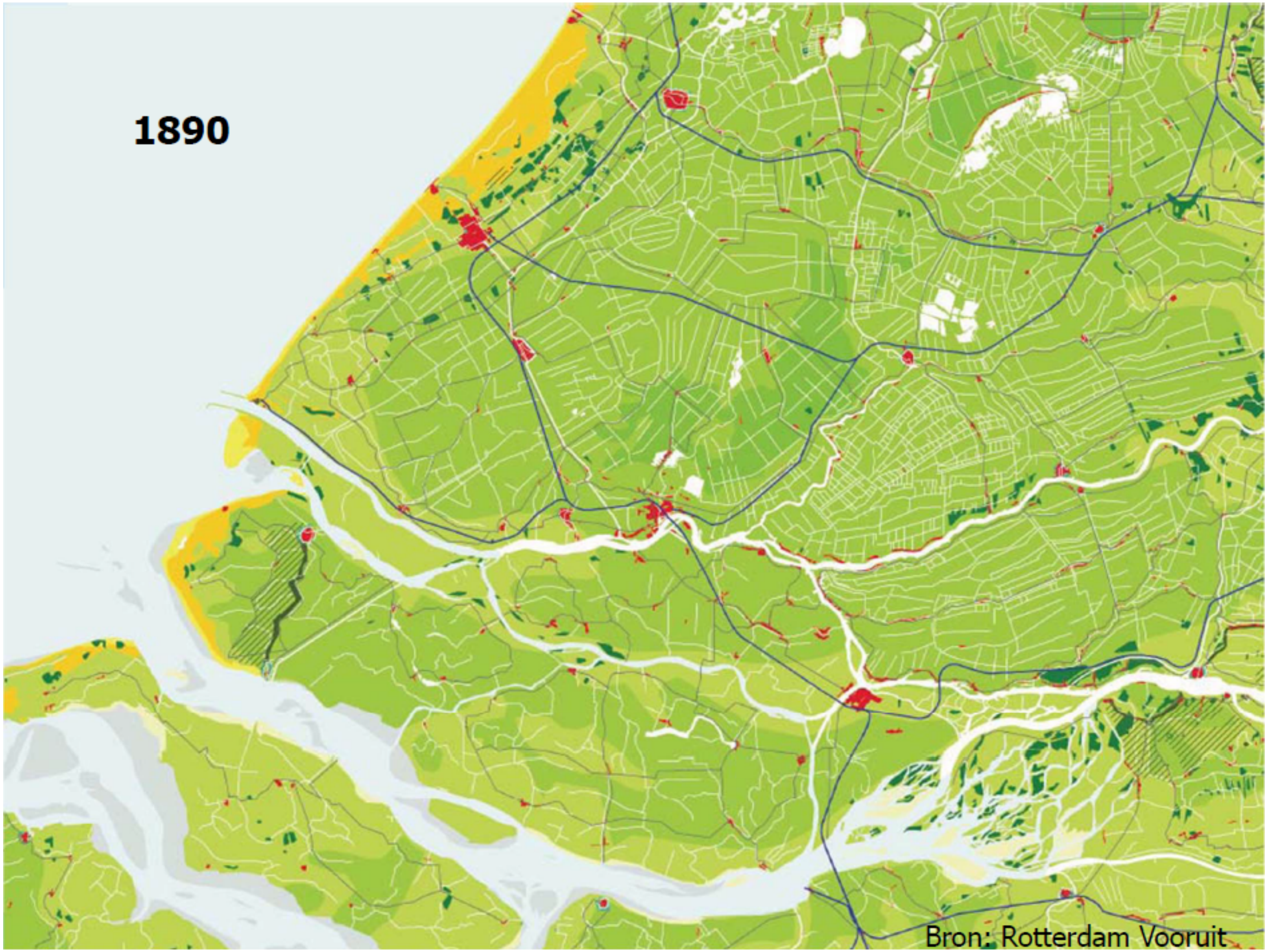

# CIE4801 Transportation and spatial modelling
## Spatial modelling: concept, descriptive models

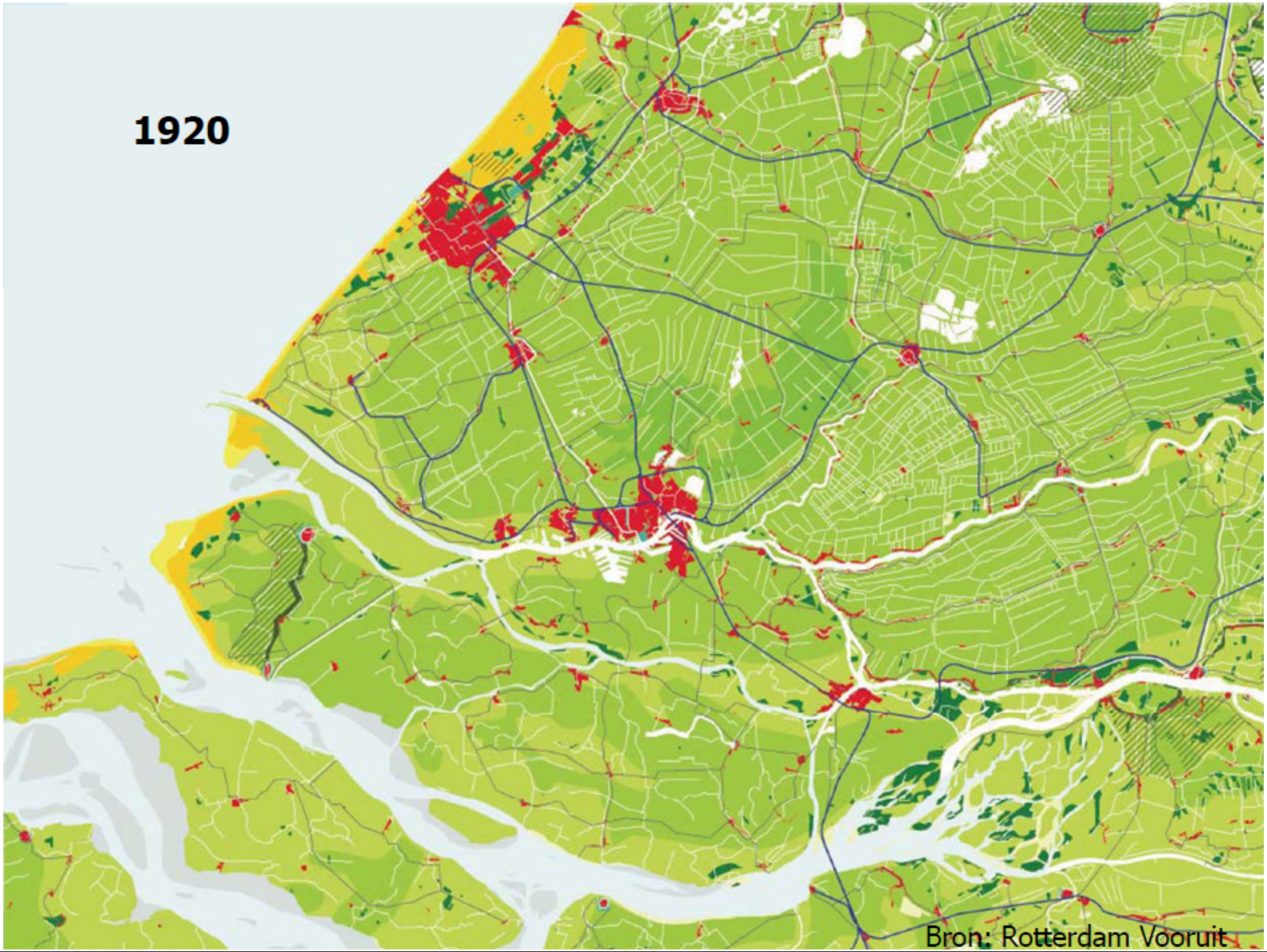
Rob van Nes, Transport & Planning

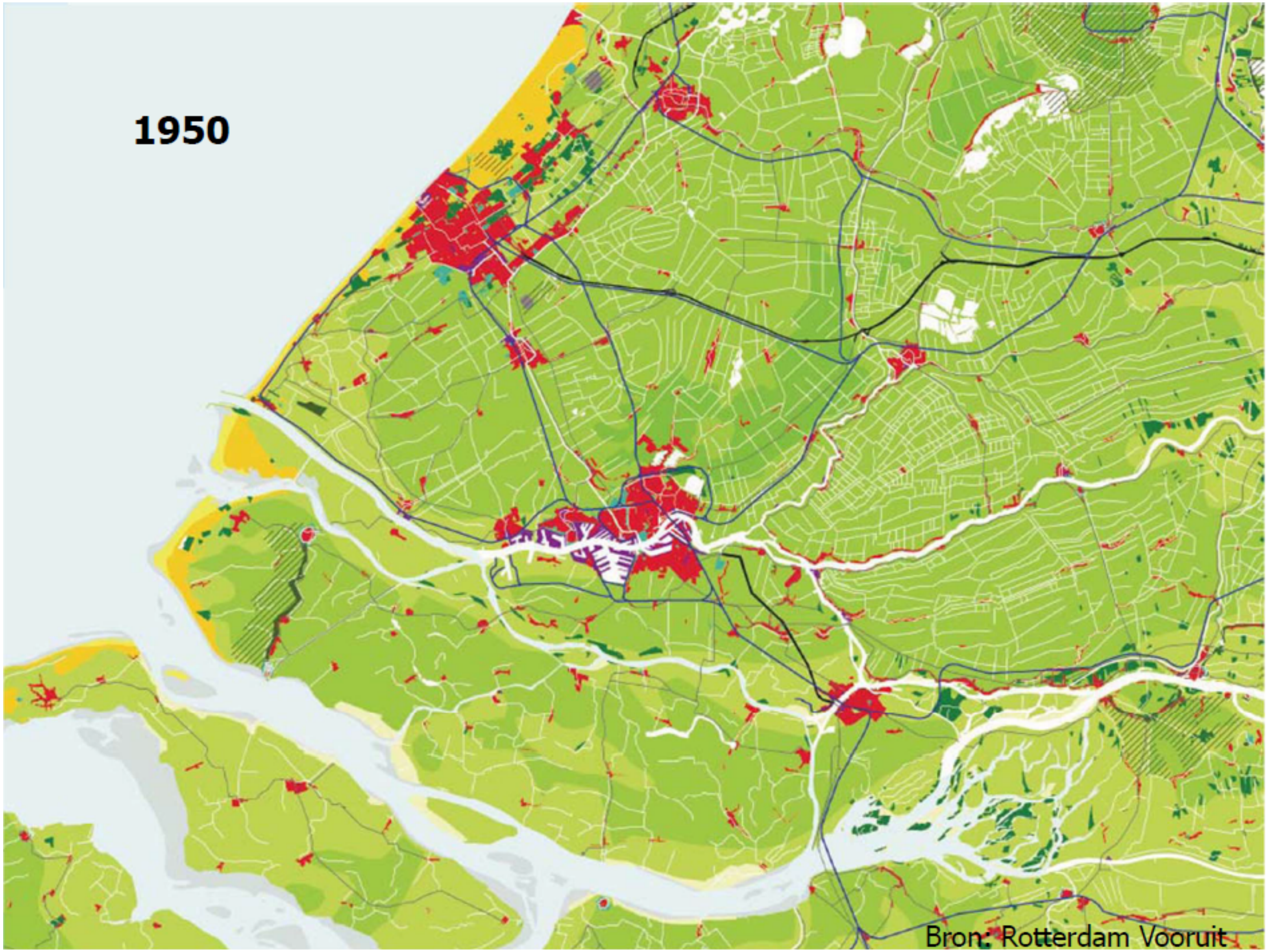
31-08-18

# Spatial modelling?

- Transport models assume a given spatial setting, e.g. for inhabitants, jobs, etc.
- Plausible for a model for a base year
- However, is it valid for a future year?
  - This depends on the measures you're evaluating!
- Two options
  - Simple strategy: use scenarios
  - Elaborate strategy: model land-use as well


1890
Bron: Rotterdam Vooruit


1920
Bron: Rotterdam Vooruit


1950
Bron: Rotterdam Vooruit


1980
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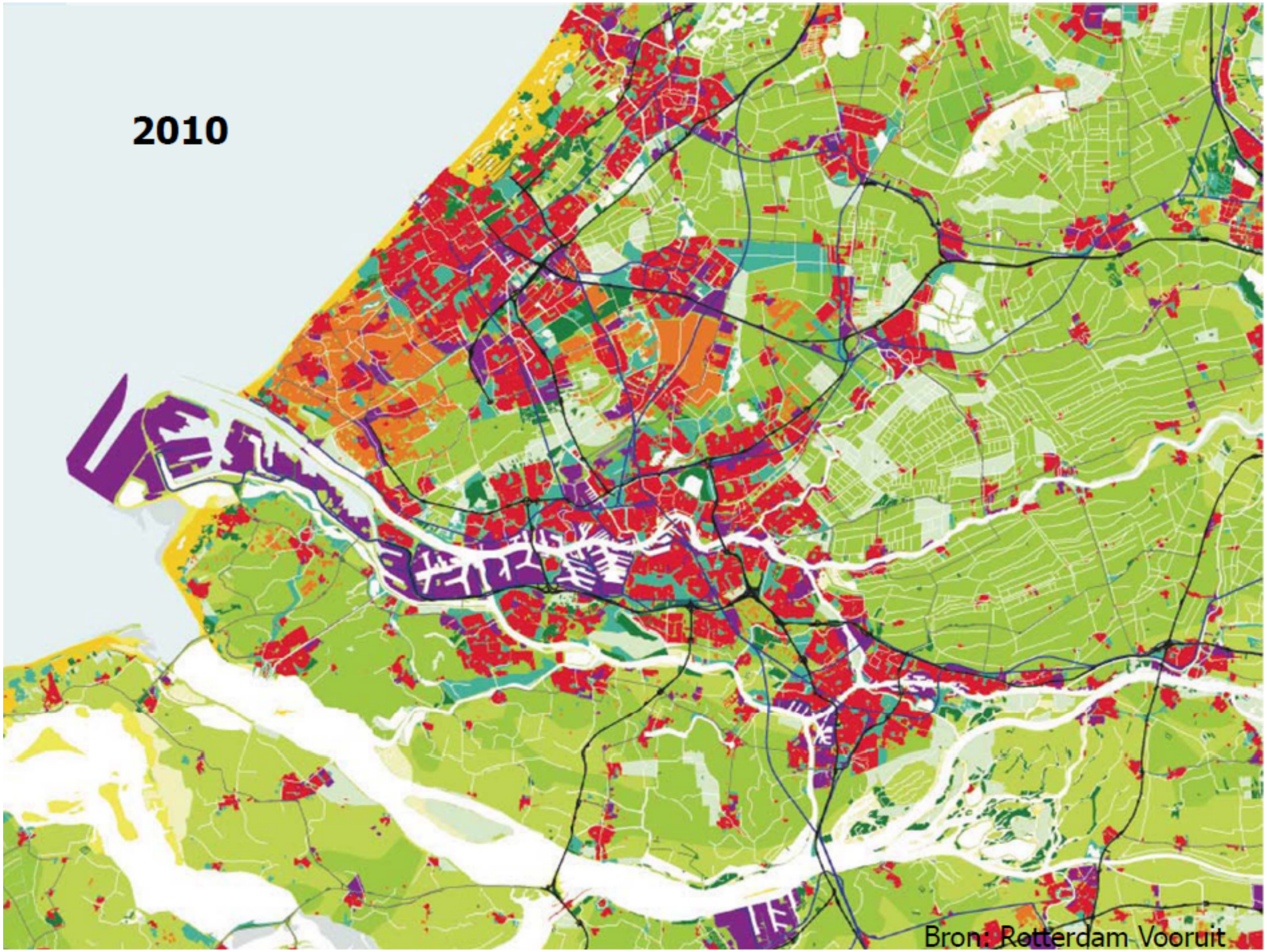

2010
Bron: Rotterdam Vooruit

# What happened?

- 1 Queen regent and 3 Queens
- 1 World war
- 2 Economic crises

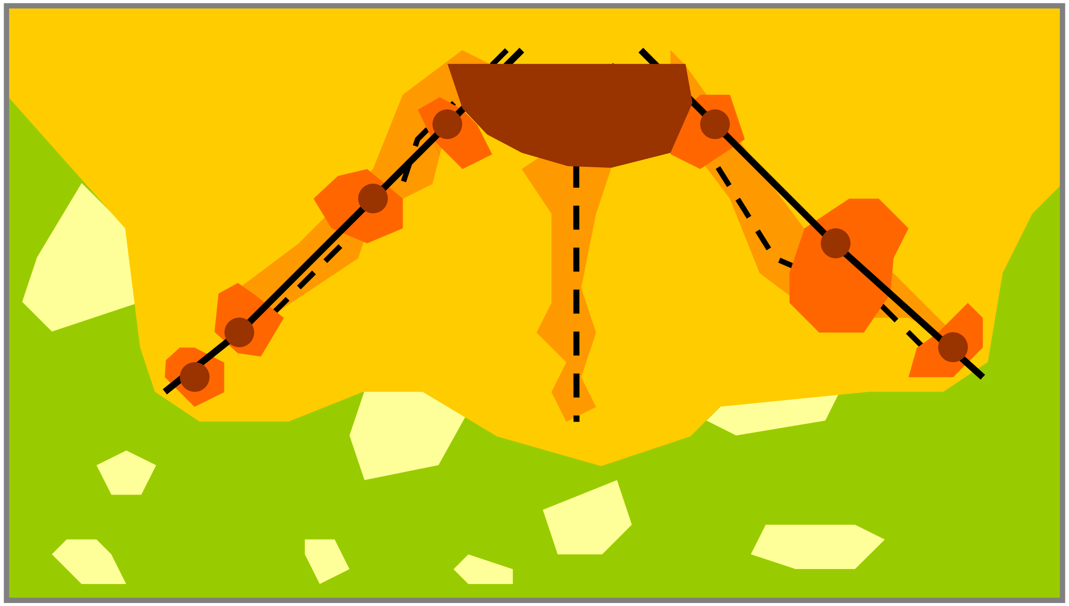
- But what about a planner's perspective?

# A planner's perspective

- Rise of the bicycle
- Rise of the tramway
- Rise of the car
- "Fall" of public transport
  - esp. regional tramway

- From less than 5 million to 16.5 million inhabitants
- From agricultural via industrial to service economy
  - Plus trade of course
- Economic growth of a factor 40

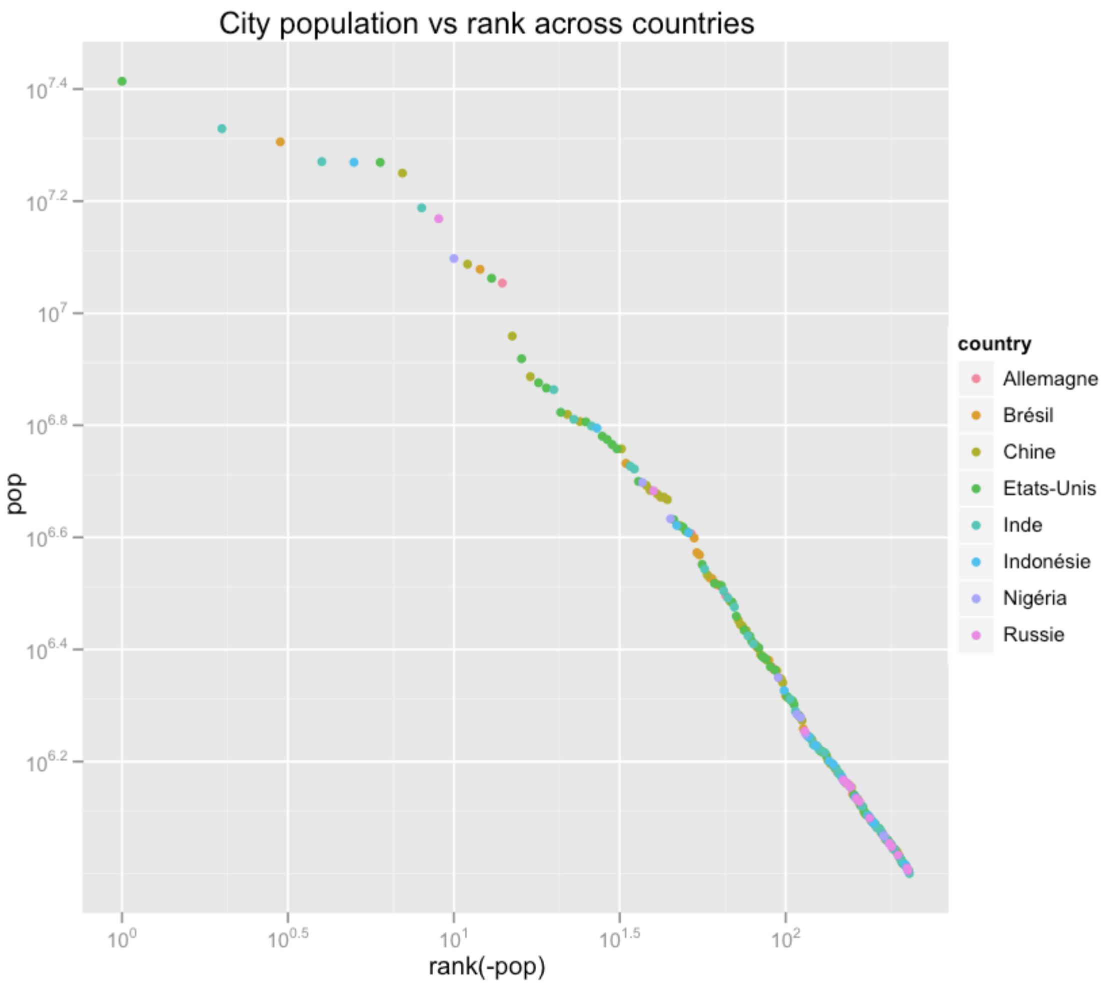
# Relationship transport and land use: Historical pattern



- Built up area prior to introduction of mechanical transport
- Development consequent on (steam) railways
- Development consequent on tramways
- Development consequent on buses
- Development consequent on private car

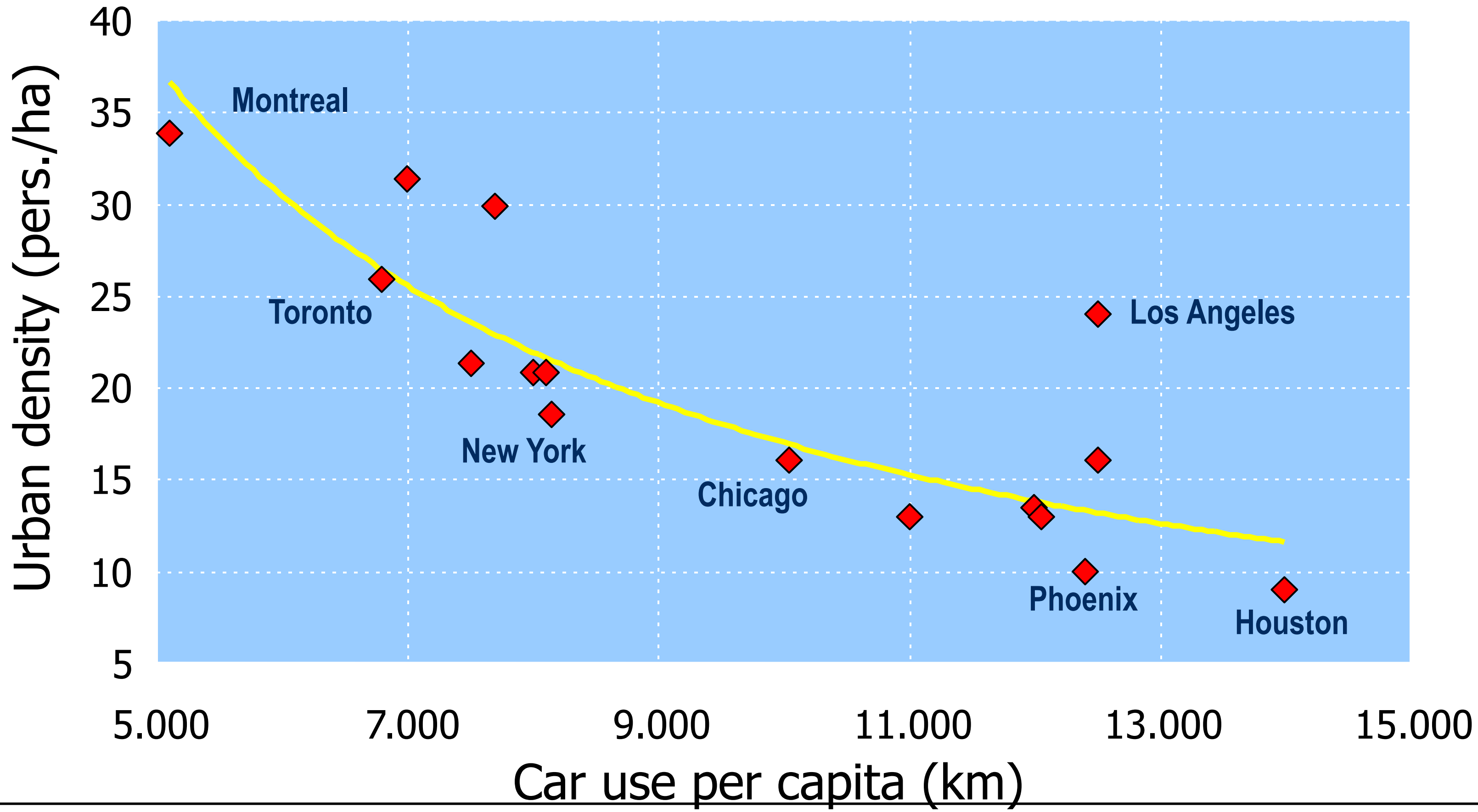
# Resulting patterns: Scale laws e.g. Zipf

- The number of cities of a size greater than N is proportional to 1/N

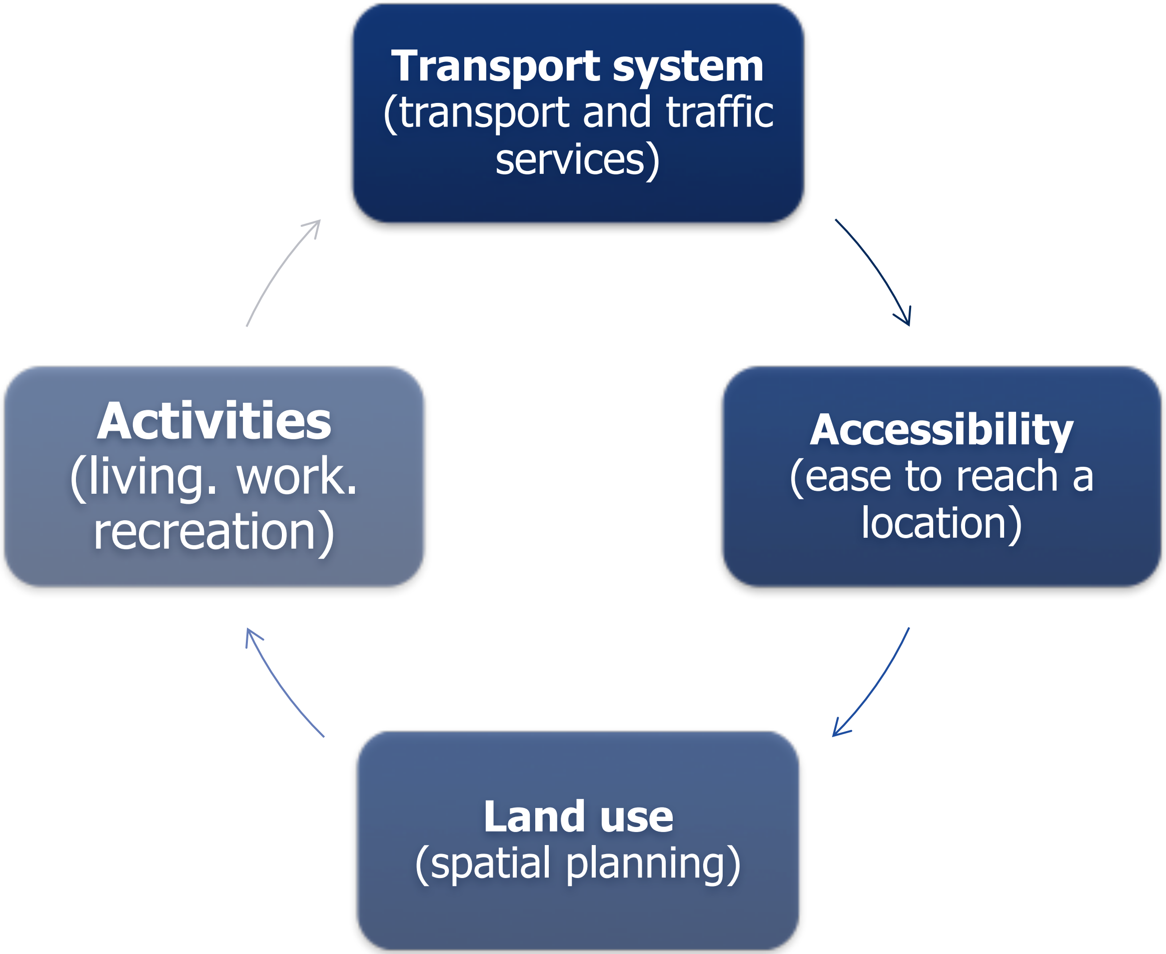



Self-organisation?

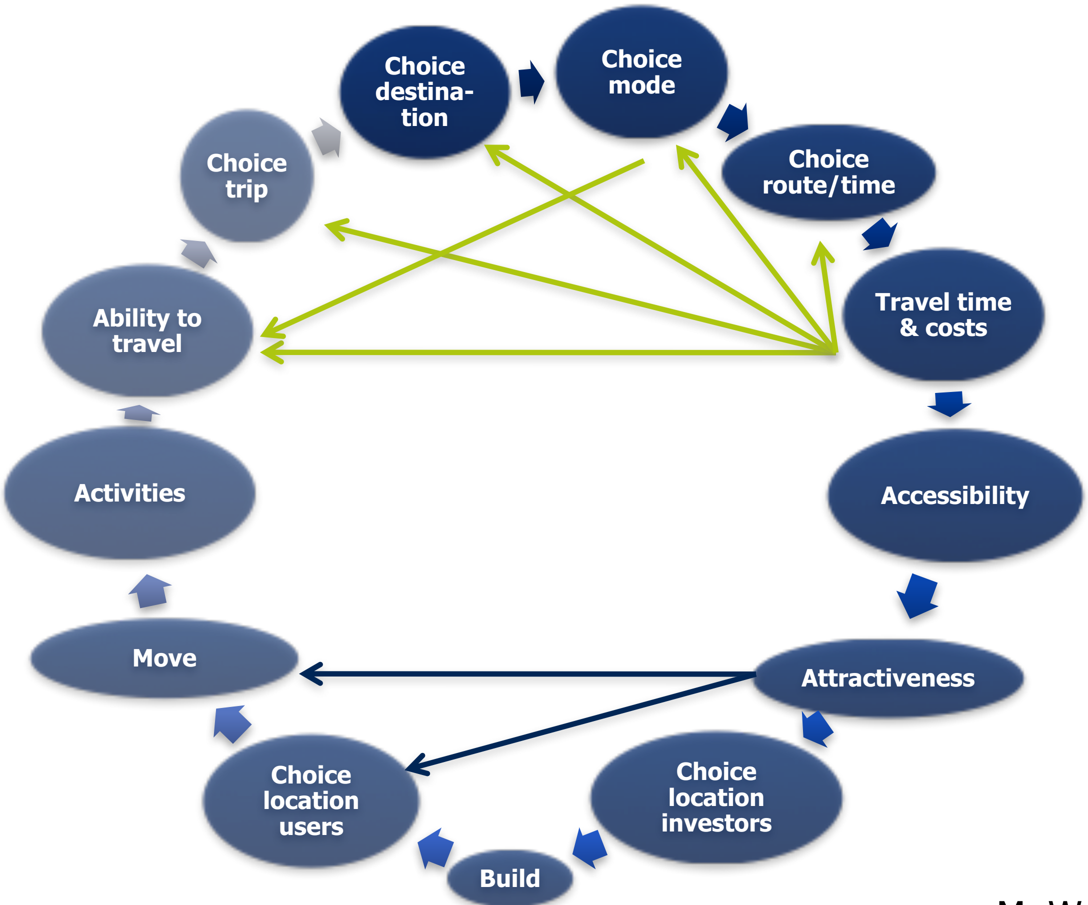
# Resulting patterns: Relationship Density and car use (North America, 1991)



# Main mechanism for the transportation and spatial system

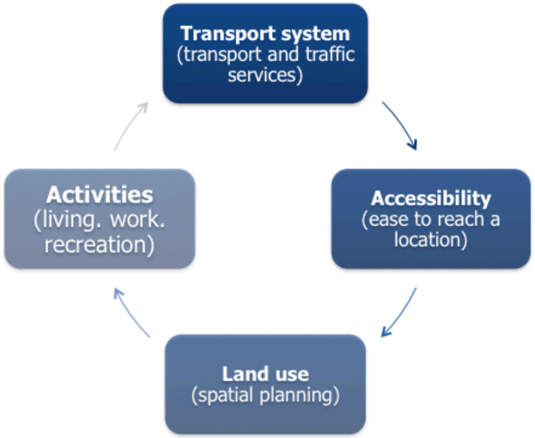


# Mechanism in more detail: Wegener's circle



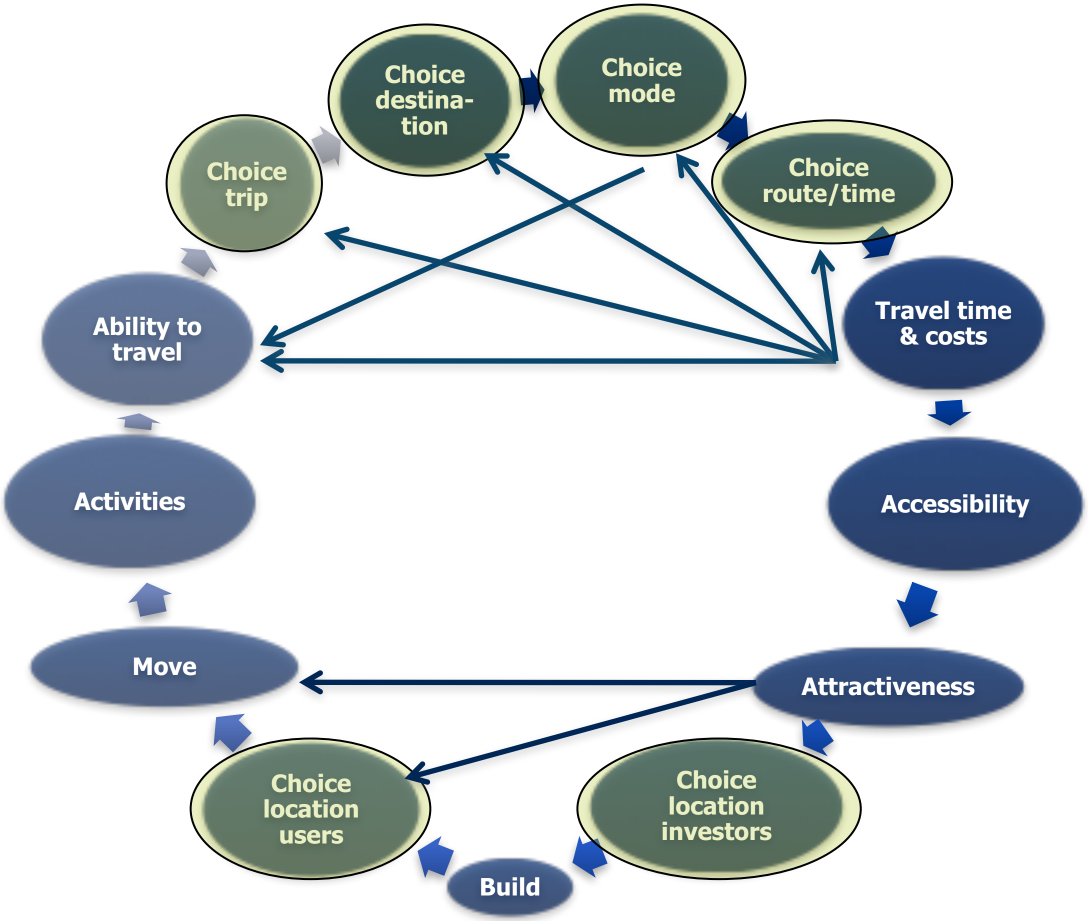

M. Wegener, 1995, 2004

# Positive and negative feedback




- Crucial element is link transport -> accessibility
- More activities lead to higher demand for transportation
- Thus for car:
  - Higher demand leads to congestion?
  - Higher demand leads to new infrastructure?
- And for public transport:
  - Higher demand leads to higher frequencies?

# Choice behaviour by different actors



# Actors and choice making

- Actors:
  - Politicians
  - Investors
  - Households
  - Firms
  - Travellers (making multiple choices)

- Long term choices versus short term choices
- Some of these choices are dominated by the transport system, some are not
- Some are public transport oriented, many are car oriented

- There are more factors influencing the system!

# Not just land-use and transport only

# Example for settlement patterns

- Local conditions play a major role for the location of settlements
  - Safety
  - Water and food
  - Natural resources
  - Politics
  - Accessibility

- Mechanisms/drivers change over time
  - Other drivers might take over
    - Law of increasing returns
  - Drivers may loose importance
    - Stand-still or decline
    - Permanent or temporary

# Content spatial modelling

Today

- Classical theory on land use
- Accessibility
    - How defined?
- Descriptive spatial models
    - Hansen-model
    - Lowry-model (O&W 15.2)

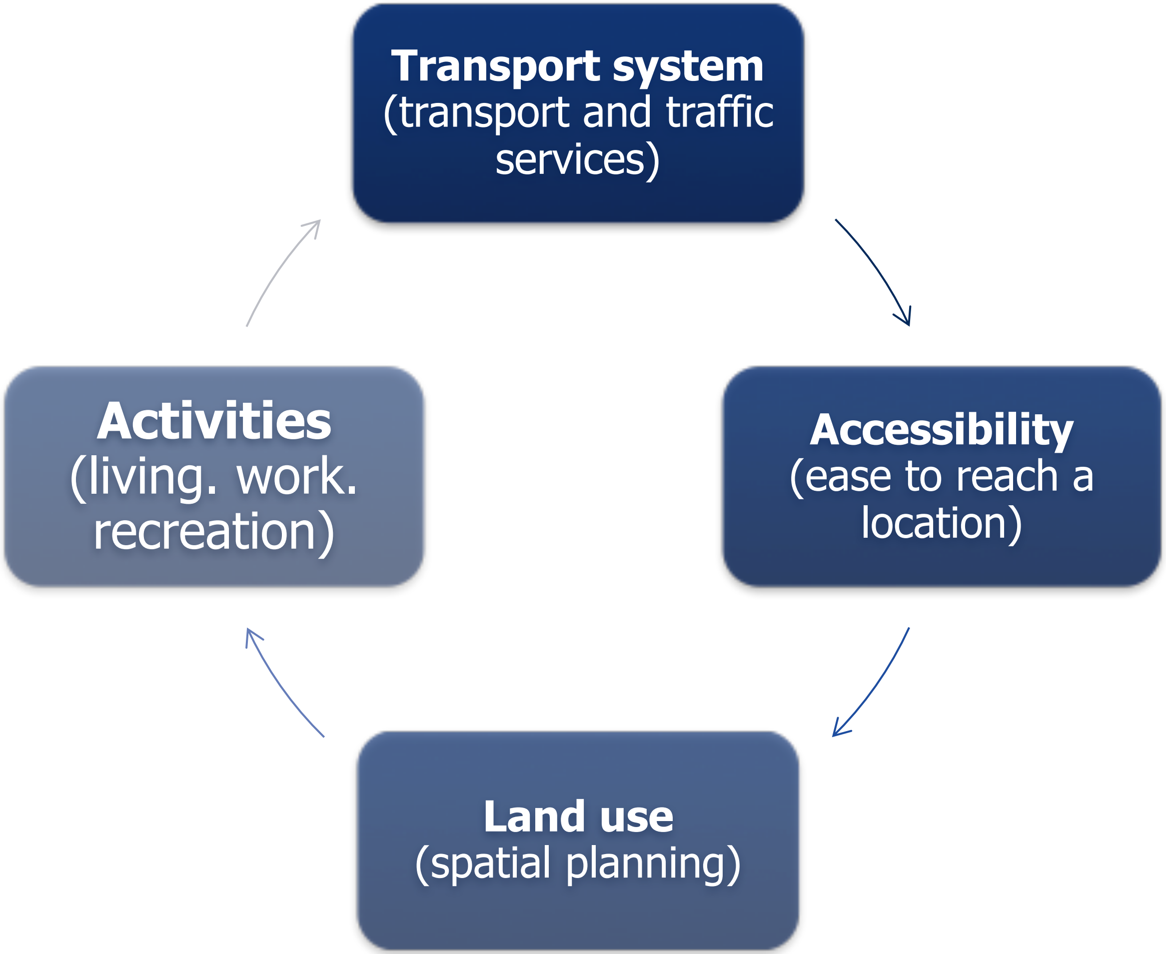
Next week

- Land use and transport interaction models
    - TIGRIS and TIGRIS XL
    - Choice modelling for household and firm allocation
- Wegener's circle: reprise

# 1.

*Classical theories on land use*

# Main mechanism for the transportation and spatial system



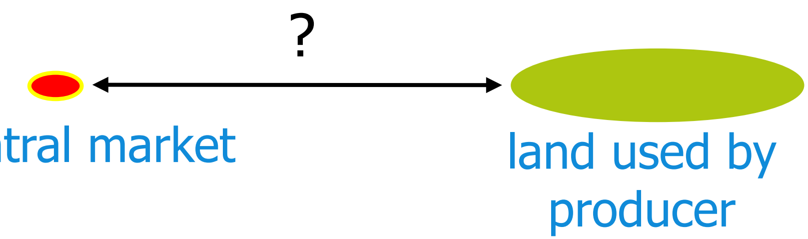
# Classical models

- Bid-rent concept: Von Thünen
- Competition for a market: Christaller
- Agglomeration effect: Hotelling

# Classical models: Von Thünen

## Single commodity model

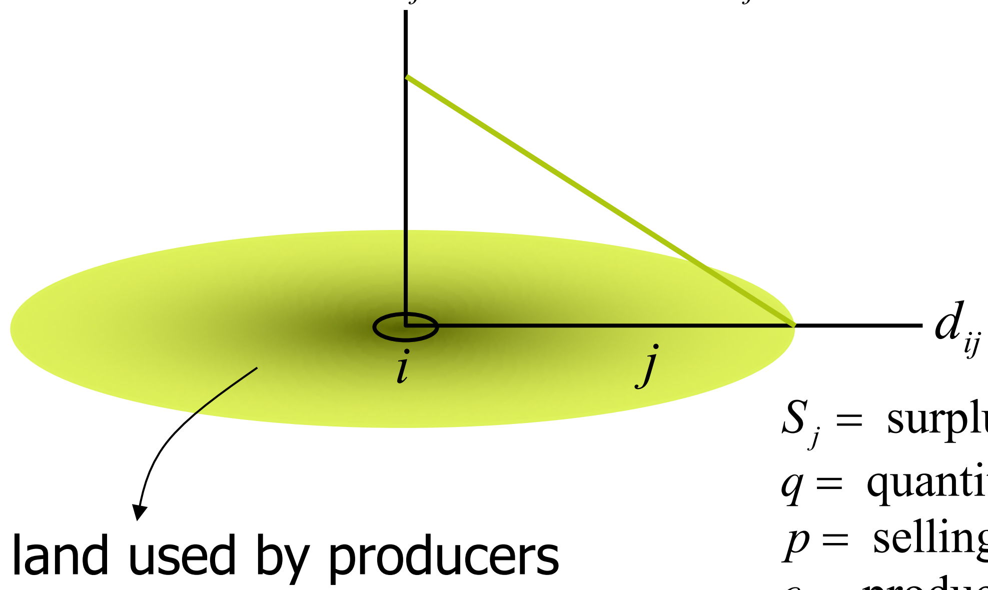
- (large number of) producers want to sell a certain agricultural commodity a central market place
- (large number of) owners rent land to the producers
- land owners let the producers bid on the land space
- producers will bid a rent with which they still can make profits




<u>Question</u>:
What rents will the producers pay for the land, and how much land will be used?

# Von Thünen: single commodity model

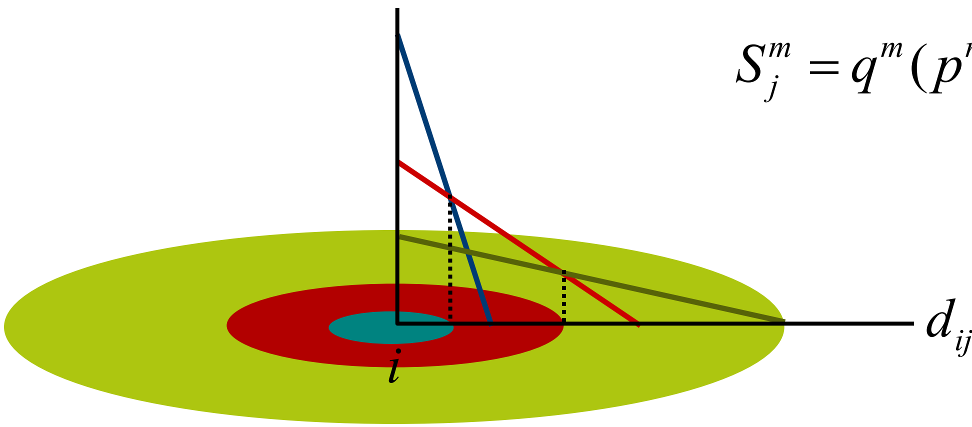
$S_j = q(p - c - kd_{ij})$ = what is left for paying rent




$S_j =$ surplus for producer
$q =$ quantity (units) produced
$p =$ selling price per unit
$c =$ production costs per unit
$k =$ transportation costs per unit per km
$d_{ij} =$ distance to central market place

# Von Thünen: Multi-commodity model

$$S_j^m = q^m(p^m - c^m - k^m d_{ij})$$




$S_j^m$ = surplus for producer of commodity $m$

$q^m$ = quantity (units) produced of commodity $m$

$p^m$ = selling price per unit of commodity $m$

$c^m$ = production costs per unit of commodity $m$

$k^m$ = transp

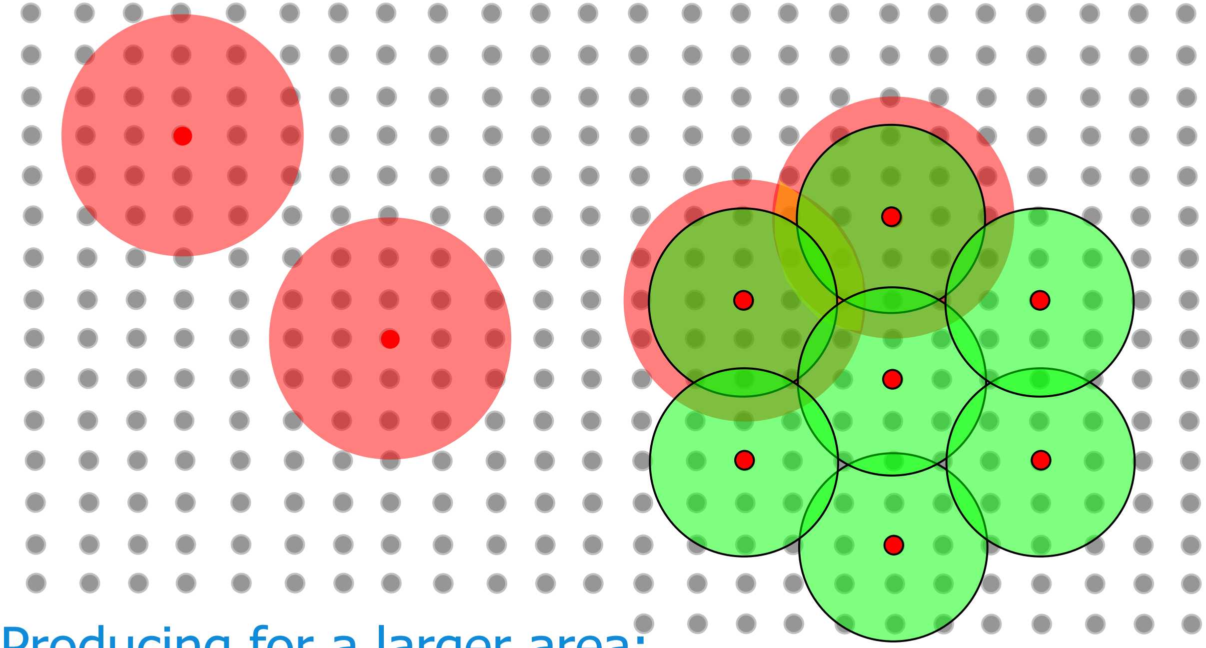
$d_{ij}$ = distan

Instead of commodities urban functions e.g. retail, manufacturing and residential can be used => bid-rent theory

# Competition for a market: Christaller (1932)

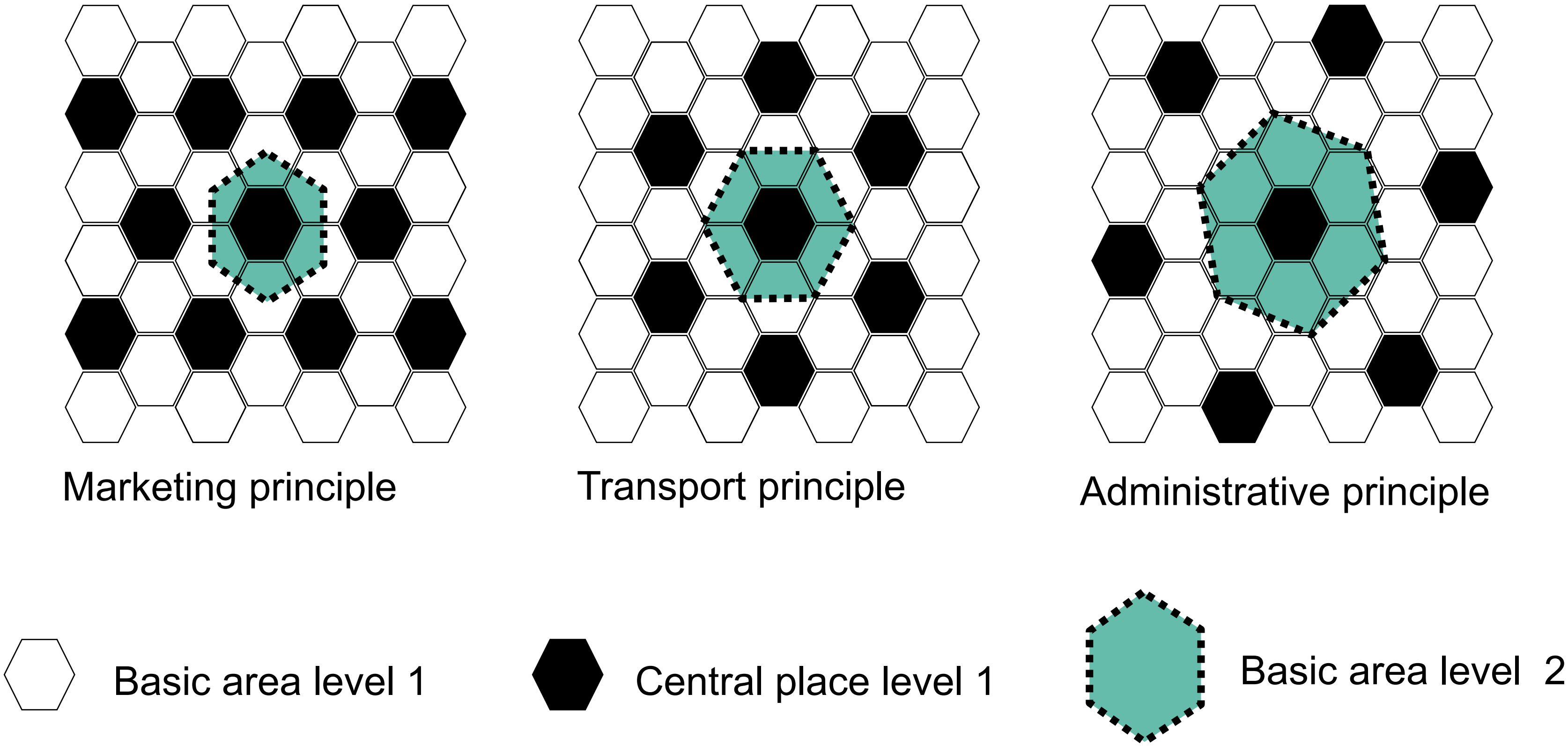
# Competition for a market: Christaller (1932)

- Evenly distributed population of self-sufficient farmers
- Farmers can produce beer for a certain area



Producing for a larger area:
- Cheaper production process
- More expensive distribution

# Spatial levels according to Christaller



# Agglomeration effect: Hotelling

Assume a beach of 1 km long where the visitors are uniformly distributed along the beach.
What are the best locations on this beach for two ice vendors?

The best location for both is the middle of the beach:
no competition on accessibility only on product and service

# Agglomeration factors

- Advantages of agglomerations
  - Positive externalities
- Associated development
  - Education, health care, financial services
- Transport is essential
- Congestion limits growth of agglomerations

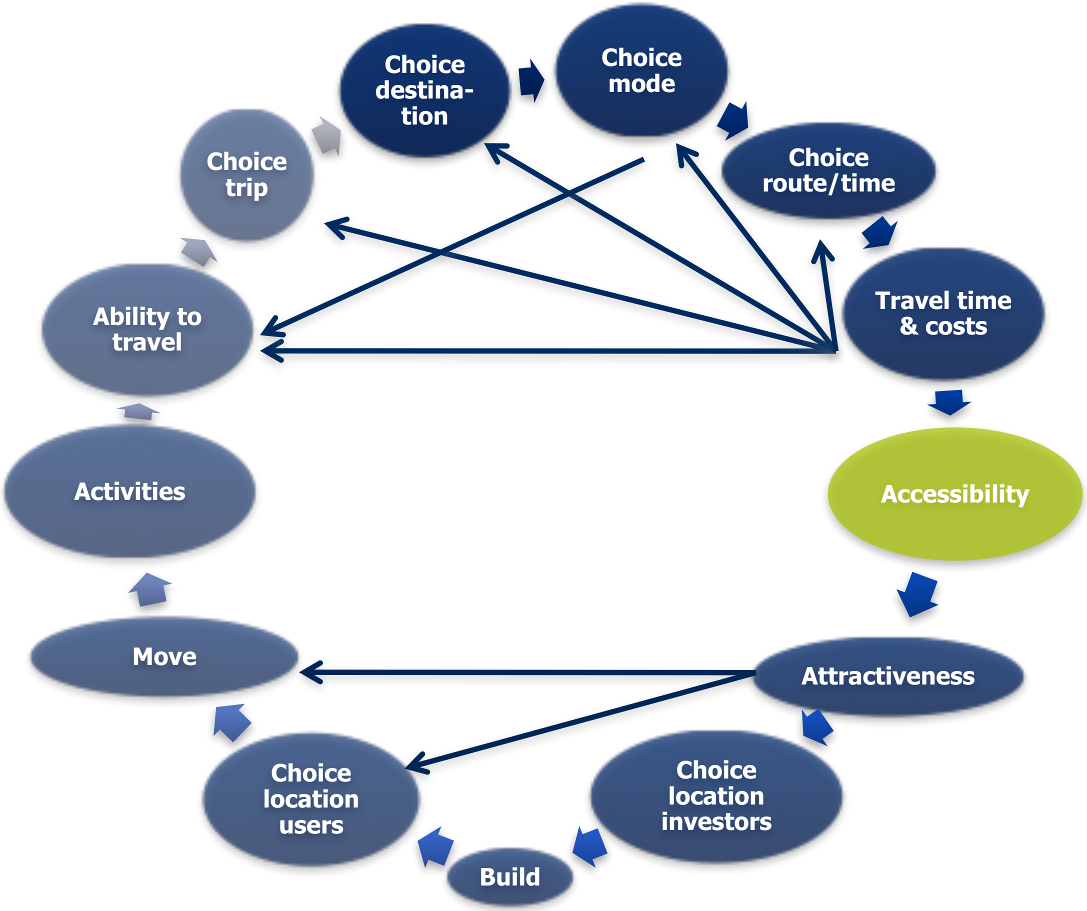
# Classical models: main findings

- Simple economic models demonstrate that transportation affects land use
- Competition of competitors for a market suggests a spatial pattern
- Competition of competitors for a market suggests the existence of agglomeration factors

# 2.

## *Accessibility*

# Accessibility in Wegener's circle




M. Wegener, 1995, 2004

# Spatial planning problem: example

- Imagine a city
- Where would you allocate a large cinema complex?
- Possible criteria
    - Location where a lot of people want to be
    - Location that is accessible

# Definitions of accessibility?

- Ease to reach a location……..
- From where
  - Specific location?
  - From all locations?
  - From all locations within a certain distance/travel time?
- By whom?
  - Individuals/households/companies at that location?
  - Possible clients/workforce
- Many definitions are possible:
  - Generic indicator: potential value of an area given its location in a network

# Generic indicator: Potential value

- Sum of all clients/jobs/etc. that can be reached within a certain distance/time:

$$PV_i = g \cdot \sum_j \left( M_j \cdot f\left(c_{ij}\right)\right), \forall j : c_{ij} \leq c_{\max}$$

- Different options for $f(c_{ij})$:

$$f(c_{ij}) = \frac{1}{c_{ij}^2} \Rightarrow PV_i = g \cdot \sum_j \frac{M_j}{c_{ij}^2}$$

$$f(c_{ij}) = e^{-\beta c_{ij}} \Rightarrow PV_i = g \cdot \sum_j M_j \cdot e^{-\beta c_{ij}}$$

# So what to use for the attributes?

- Choice for $M$ depends on perspective
  - Active accessibility: where you can go to
    e.g. the number of jobs you can reach from your home
  - Passive accessibility: who can reach you
    e.g. number of clients that can reach you

- Choice for $c_{ij}$:
  - Time, distance, generalised costs, logsum over modes….

- Note the similarity with trip distribution topics

# 3.1

## *Descriptive spatial models: Hansen-model*

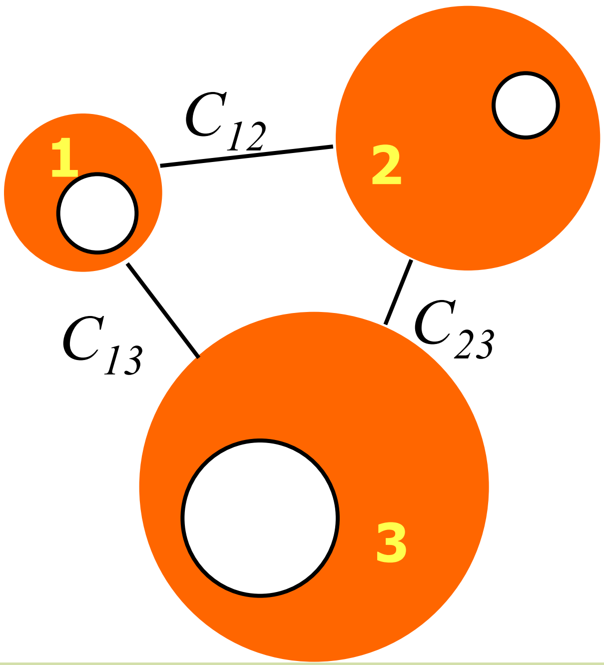
# What is it for?

- Given the network and the location of the jobs
- What is the location of the inhabitants?
- Main assumption: people prefer a location having the highest accessibility
- However, there's not always enough space available
- Inhabitants are distributed based on the product of accessibility and capacity

Hansen W.G. (1959), How Accessibility Shapes Land Use, Journal of the American Institute of Planners, Vol. 25, No. 2, pp. 73-76

# Hansen-model

Assuming an increase of the population, e.g. $\Delta R$ inhabitants,
Where will they settle?




- Number of jobs, $M_j$
- Available space, $L_j$
- $C_{ij}$ Costs between zones $i$ and $j$

Accessibility of zone $i$ is e.g.

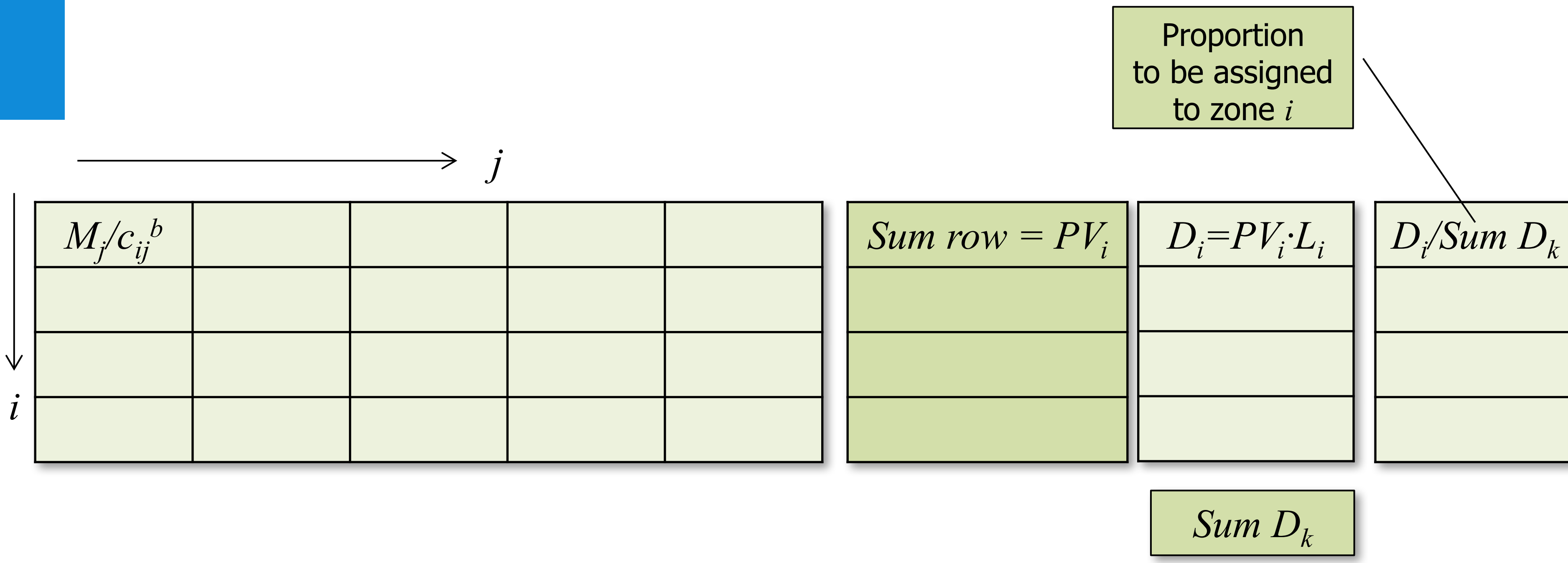
$$PV_i = \sum_{j=1}^{n} \frac{M_j}{c_{ij}^b}$$

The increase in inhabitants in zone $i$ is

$$\Delta R_i = \Delta R \frac{PV_i \cdot L_i}{\sum_{j=1}^{n} PV_j \cdot L_j}$$

Note that you can distribute jobs as well.
In that case you should use inhabitants for $M$.

# Hansen model



# 3.2

## *Descriptive spatial models: Lowry-model*

# Lowry model: different types of jobs

- Distinction between basic jobs and service jobs
  - Basic jobs: location bound e.g. industry, government,
  - Service jobs: dependent on population e.g. education, health care, retail

- Two main assumptions
  - Fixed ratio between population and jobs: $u$
  - Fixed ratio between service jobs and population: $v$

- Travel costs are symmetric

Lowry, I.S. (1964), A Model of Metropolis, RAND Memorandum 4025-RC

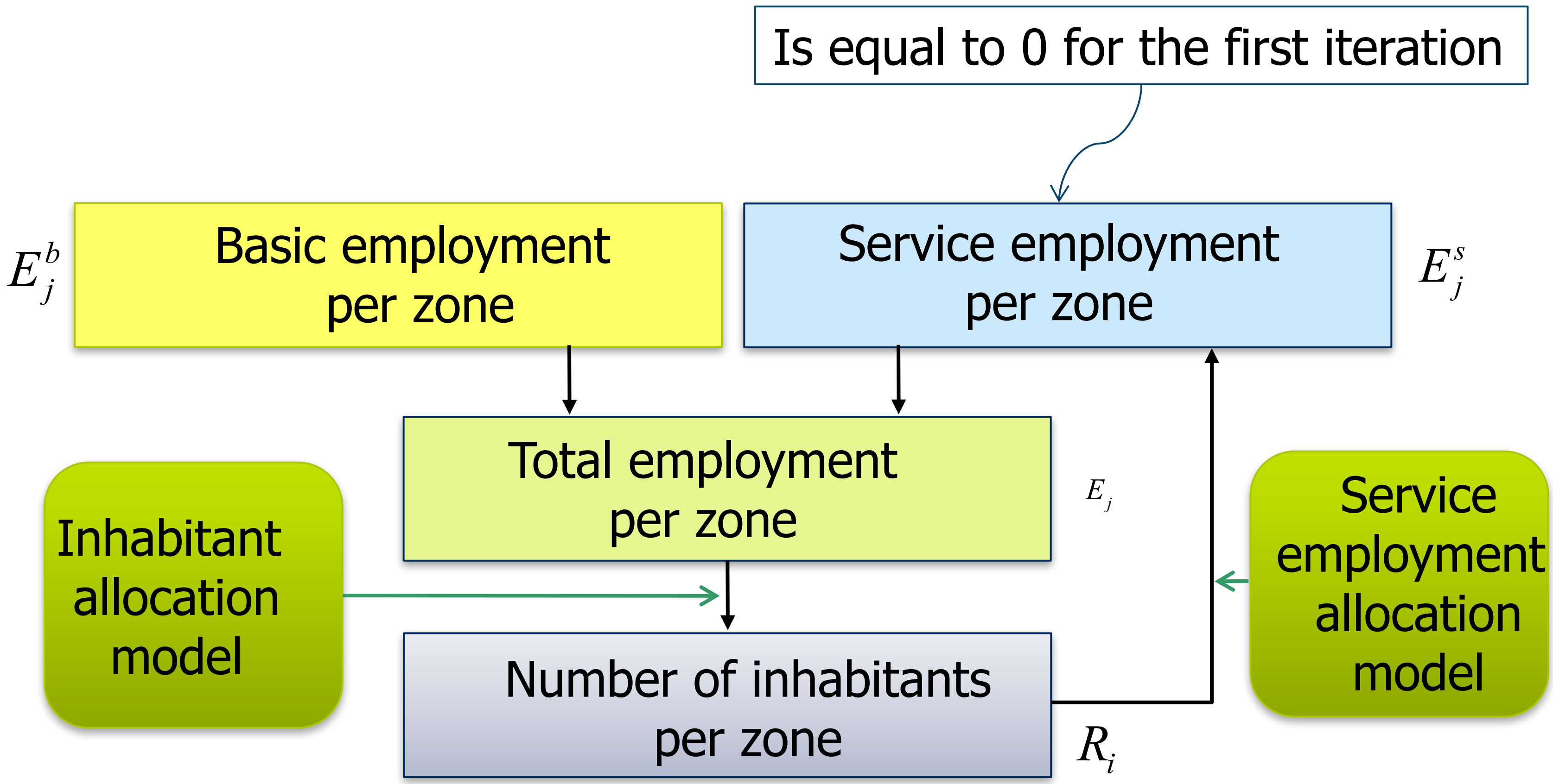
# Lowry model: the method

- Given is the network en the distribution of the basic jobs, as well as both ratios $u$ and $v$

- Stepwise approach
  1. Determine and distribute workers (population) based on basic jobs
  2. Determine and distribute service jobs based on the population
  3. Determine and distribute workers (population) based on total of service jobs and basic jobs
  4. Repeat steps 2 and 3 until sufficient convergence is achieved

- The distribution of workers or service jobs is based on the contribution of a zone to the potential value (=accessibility) of the zone that is considered

# Lowry-model: flow chart



# Example Lowry-model

Given is a simple case consisting of two zones:


In zone A there are 1200 base jobs, in zone B there are none. For simplicity sake the attractiveness for inhabitants is equal to the attractiveness for service jobs: the attractiveness of zone A is 1 and attractiveness of zone B is 8. Furthermore, the function *f* used to determine the accessibility is $1/c_{ij}^2$.
The factor for inhabitants versus workers is 2, and the factor for service jobs versus inhabitants is 0.1. The travel costs are given in the following table:

| | A | B |
|---|---|---|
| A | 1 | 2 |
| B | 2 | 1 |

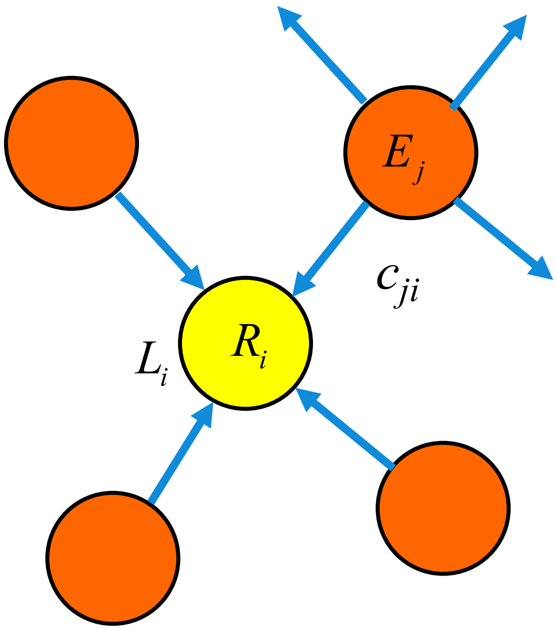
(a) Use this simple case to demonstrate the way the Lowry model works for the first two steps, i.e. until the algorithm starts to iterate.

# Lowry model:
## Allocation inhabitants (from $j$ to $i$)

- Starting point are the jobs in zones $j$
- For every zone $j$
  - Distribute the workers of zone $j$ over zones $i$ using the contribution of zone $i$ to the potential value (accessibility) for living of zone $j$
    - Note that zone $j$ is an option too
- Sum for each zone $i$ the workers from all zones $j$ and determine the total population in zone $i$

Note that in this notation we will assume that $j$ refers to jobs and $i$ to inhabitants

# Lowry-model:
## Allocation inhabitants in zone *i* for work zones *j*

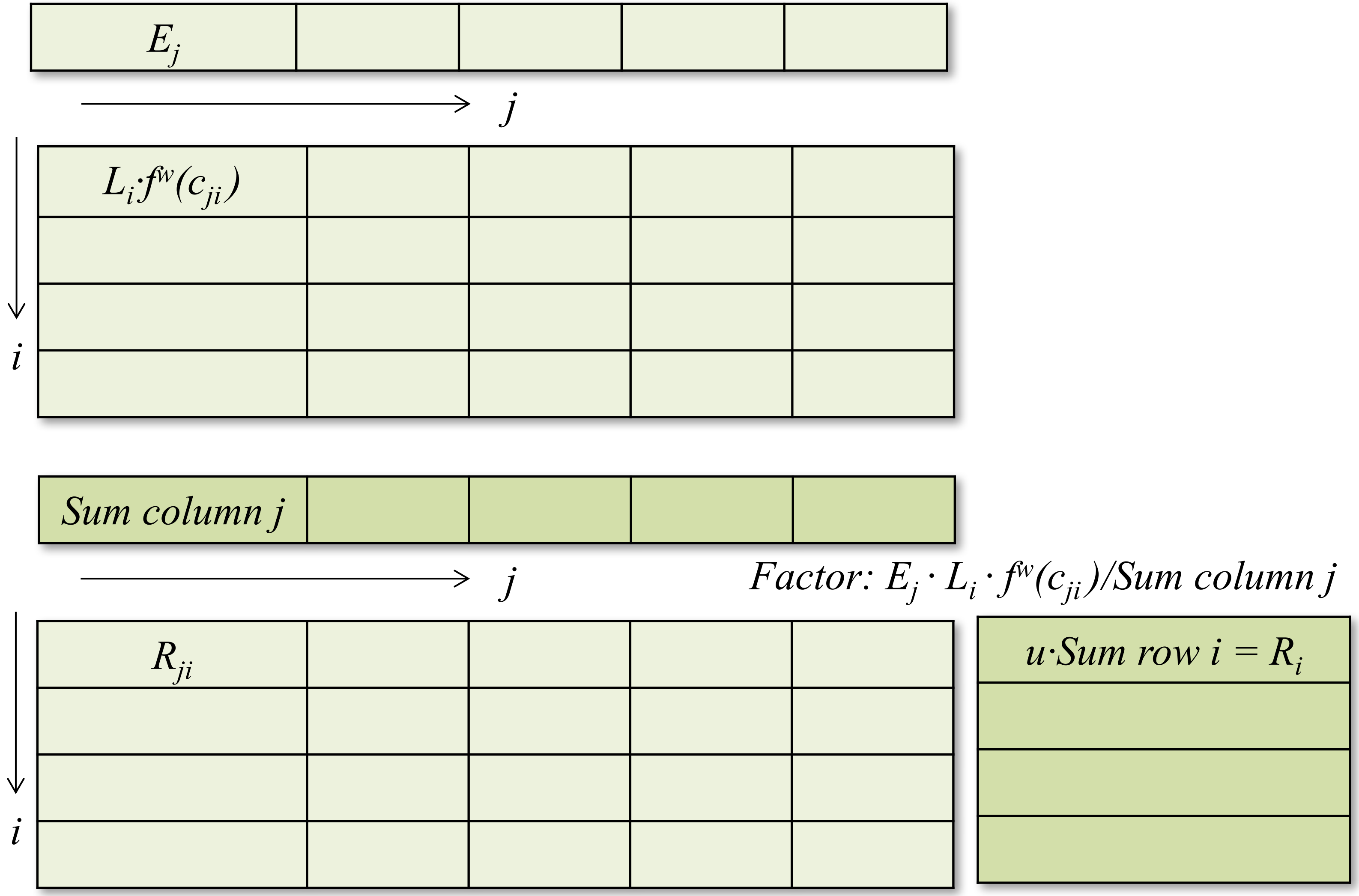



$$R_{ji} = E_j \frac{L_i \cdot f^w(c_{ji})}{\sum_{k=1}^{n} L_k \cdot f^w(c_{jk})}$$

$$R_i = u \cdot \sum_{j=1}^{n} R_{ji}$$

$u$ = ratio between population and jobs
$E_j$ = total employment in $j$
$R_i$ = inhabitants in $i$
$L_i$ = attractiveness of zone $i$ for inhabitants
$c_{ji}$ = transport costs between $j$ and $i$

# Lowry model: distribution workers

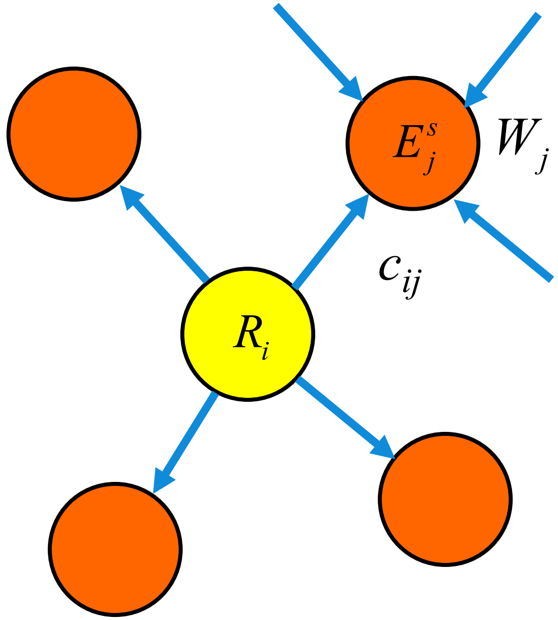


# Lowry model:
## Allocation service jobs (from *i* to *j*)

- Starting point is the population in zones *i*
- For every zone *i*
  - Determine the number of service jobs needed for the inhabitants in zone *i* and assign these service jobs to zones *j* based on the contribution of zone *j* in the potential value (accessibility) for service jobs of zone *i*
    - Note that zone *i* is an option too
- Sum for each zone *j* the service jobs from all zones *i*

# Lowry-model:

## Allocation service jobs for zone *j* for residential zones *i*



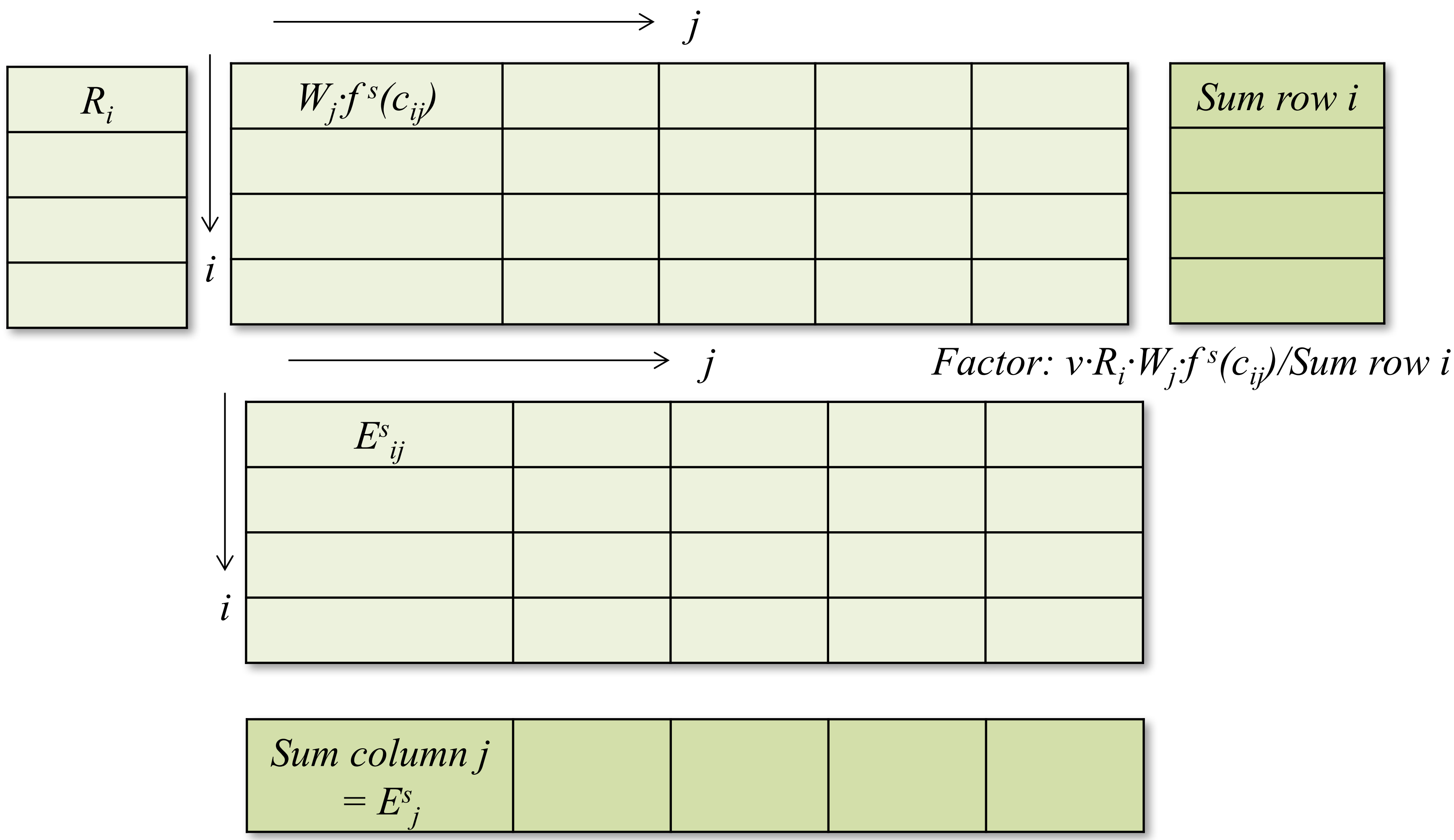

$$E^s_{ij} = v \cdot R_i \frac{W_j \cdot f^s\left(c_{ij}\right)}{\sum_{k=1}^{n} W_k \cdot f^s\left(c_{ik}\right)}$$

$$E^s_j = \sum_{i=1}^{n} E^s_{ij}$$

$v$ = ratio service jobs and population
$E^s{}_j$ = service employment in *j*
$R_i$ = inhabitants in *i*
$W_j$ = attractiveness of zone *j* for service jobs
$c_{ij}$ = transport costs between *i* en *j*

In order to account for agglomeration effects $W_j$ could equal $E^s{}_j$ of the previous iteration

# Lowry model: distribution service jobs



# Example Lowry

| | | | | | | |
|---|---|---|---|---|---|---|
| | | basic jobs | attractiver | factor inha | factor service jobs | |
| | A | 1200 | 1 | 2 | 0.1 | |
| | B | 0 | 8 | | | |
| travel costs | | A | B | | | |
| | A | 1 | 2 | | | |
| | B | 2 | 1 | | | |
| 1/travel costs^2 | | | | | | |
| | | A | B | | | |
| | A | 1 | 0.25 | | | |
| | B | 0.25 | 1 | | | |
| accessibility workers | | A | B | | | |
| 1 | A | 1 | 0.25 | | | |
| 8 | B | 2 | 8 | | | |
| | PV | 3 | 8.25 | | | |
| distribution workers b | | 1200 | 0 | | from j to i | |
| | | A | B | Total | | |
| | A | 400 | 0 | 400 | | |
| | B | 800 | 0 | 800 | | |
| zone data | | basic jobs | attractiver | inhabitant: | service jobs required | |
| | A | 1200 | 1 | 800 | 80 | |
| | B | 0 | 8 | 1600 | 160 | |
| accessibility service j | | 1 | 8 | | | |
| | | A | B | | | |
| | A | 1 | 2 | 3 | | |
| | B | 0.25 | 8 | 8.25 | | |
| distribution service jo | | A | B | | from i to j | |
| 80 | A | 26.7 | 53.3 | | | |
| 160 | B | 4.8 | 155.2 | | | |
| | Total | 31.5 | 208.5 | | | |
| zonedata iteration 1 | | basic jobs | service job | inhabitants | | |
| | A | **1200** | **31.5** | **800** | | |
| | B | **0** | **208.5** | **1600** | | |

# Concluding comments Lowry-model

- In every iteration the number of service jobs and thus the population increases
- As the algorithm convergences, it leads to an equilibrium
- $R_{ji}$ is in fact the OD-matrix for commuters in the evening peak
- Given the choice for the functions $f$ there's a clear similarity with the gravity model
  - Singly or doubly constrained?
- Concept of distinguishing basic jobs and service jobs and using a stepwise approach are still applied in some land-use models