

**MIT**

# The 4-Step Demand Model

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Urban Transportation Planning  
MIT Course 1.252j/11.380j  
Fall 2002

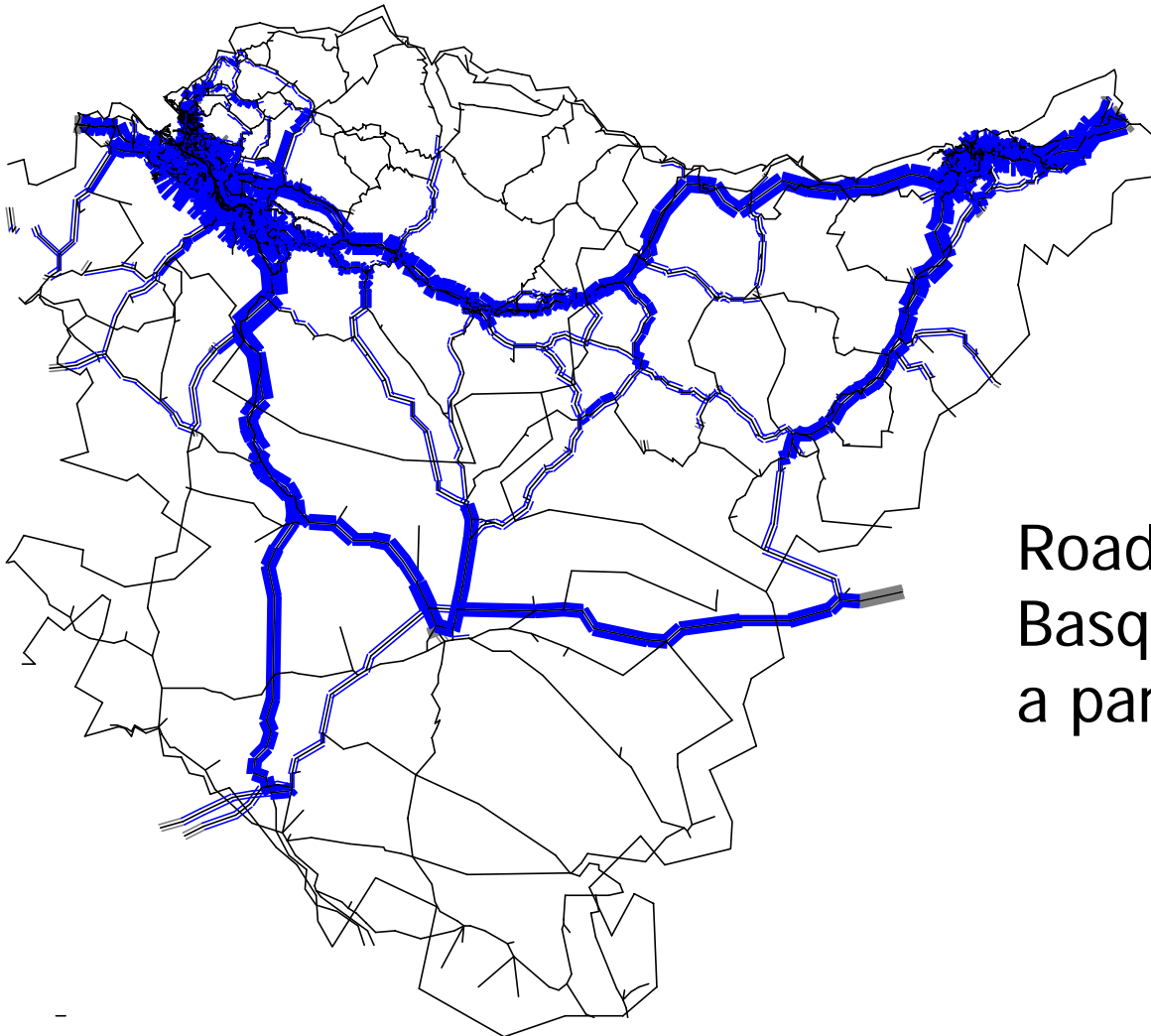
Mikel Murga, MIT Research Associate

**October 4 , 2002**

- The 4-Step Model
- Critique
- Integration of the analytical chain
- New Trends

# 4-Step Planning Model

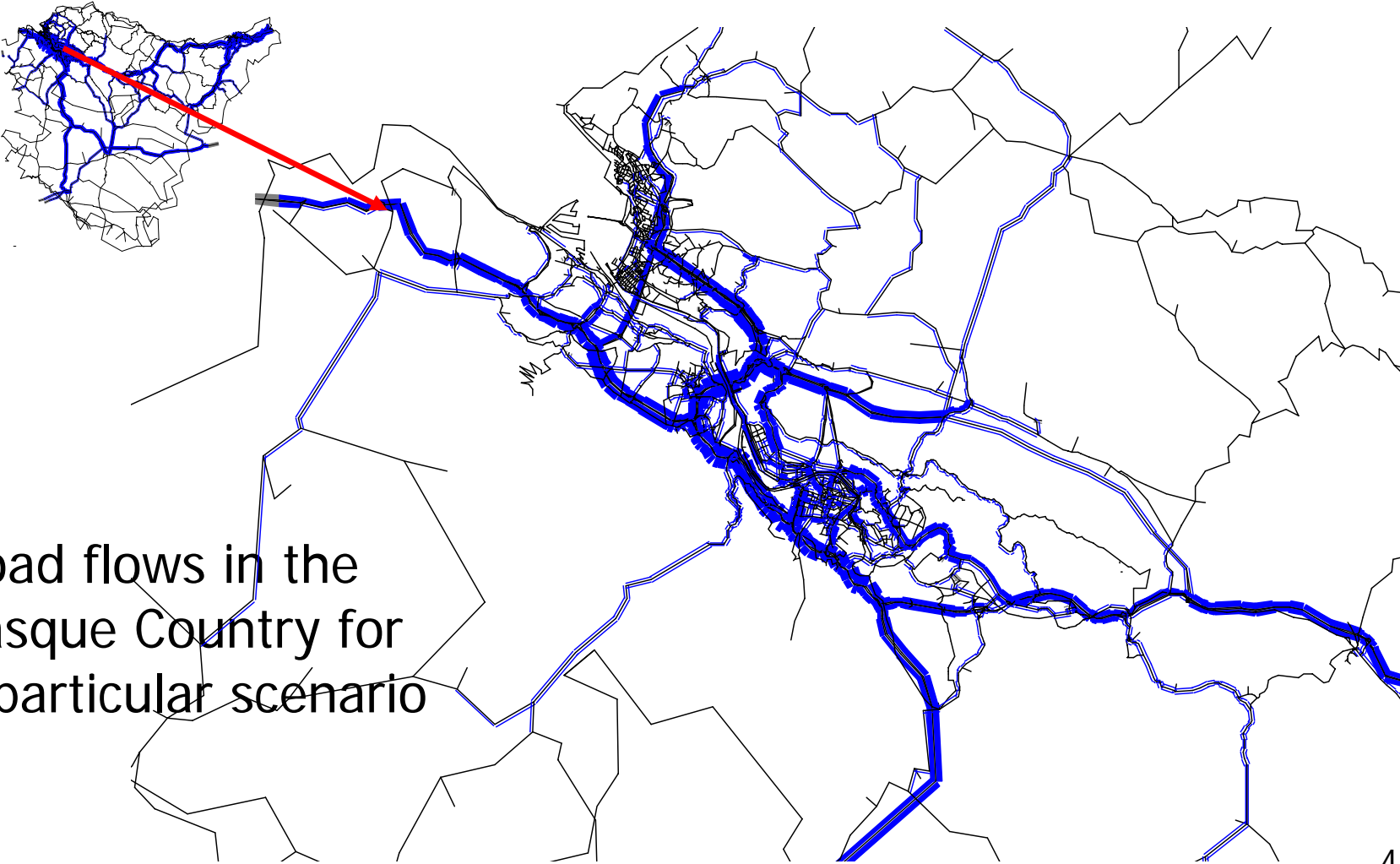
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Road flows in the  
Basque Country for  
a particular scenario

# 4-Step Planning Model

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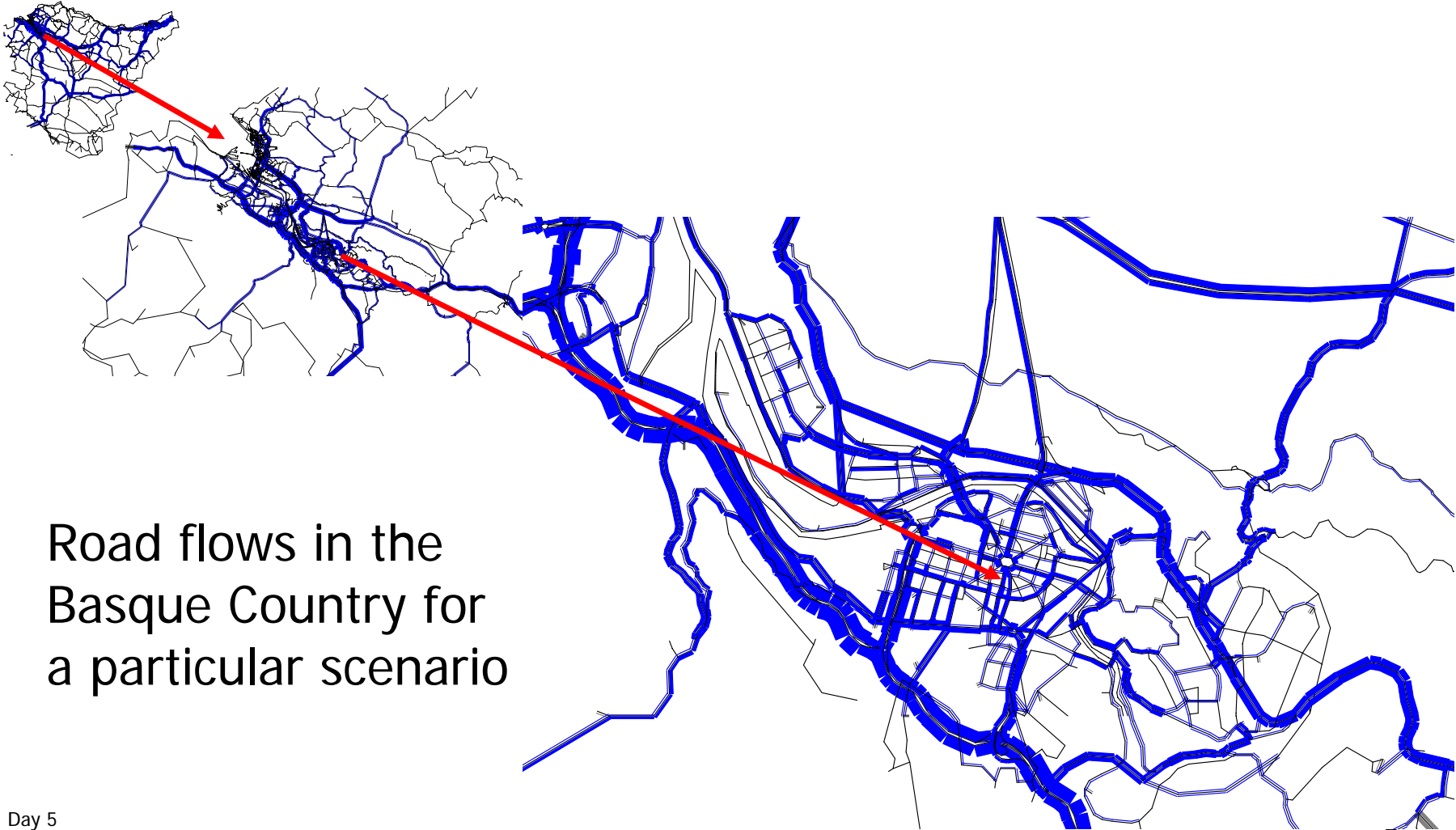


Road flows in the Basque Country for a particular scenario



# 4-Step Planning Model

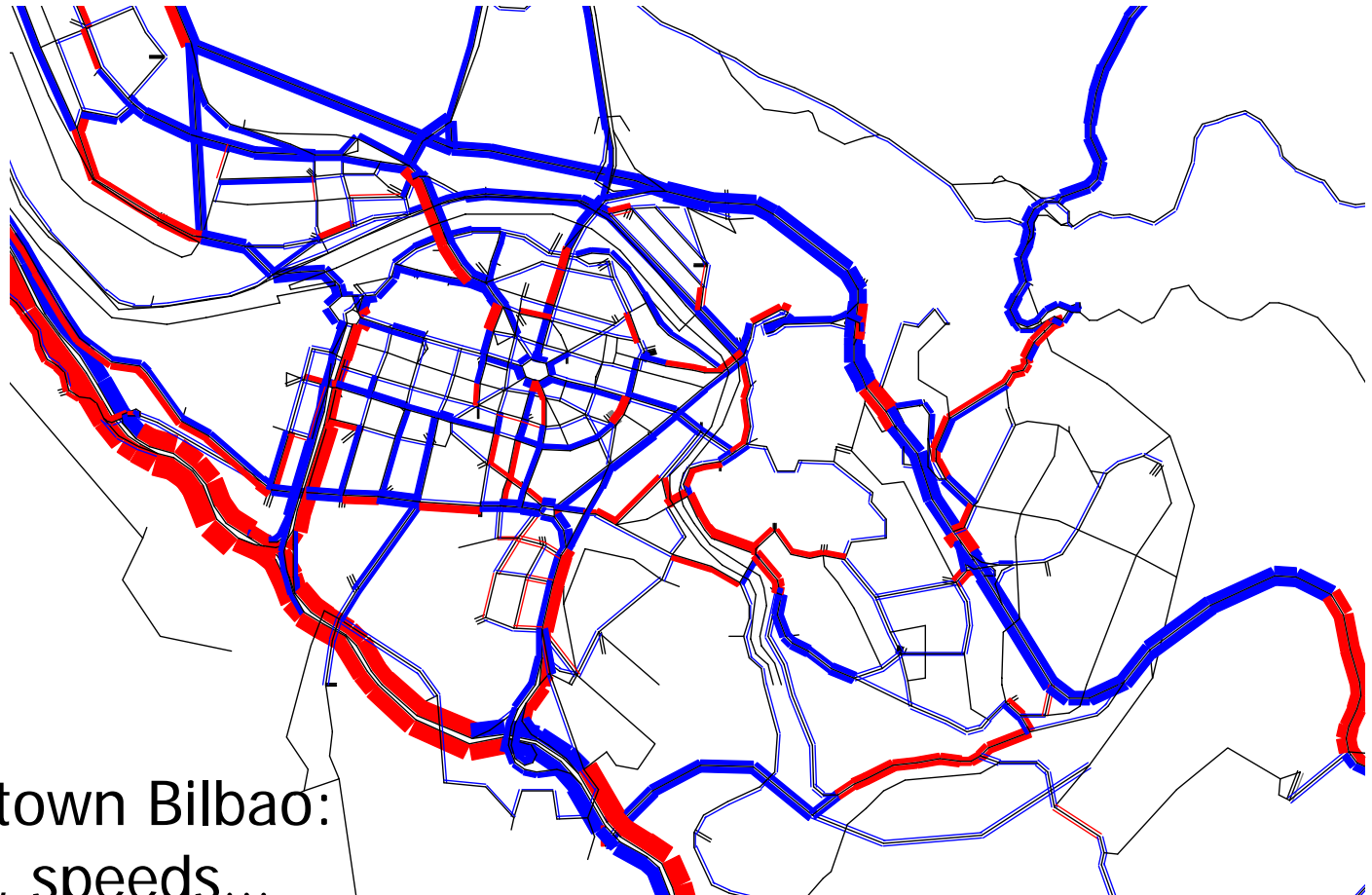
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Road flows in the Basque Country for a particular scenario

# 4-Step Planning Model

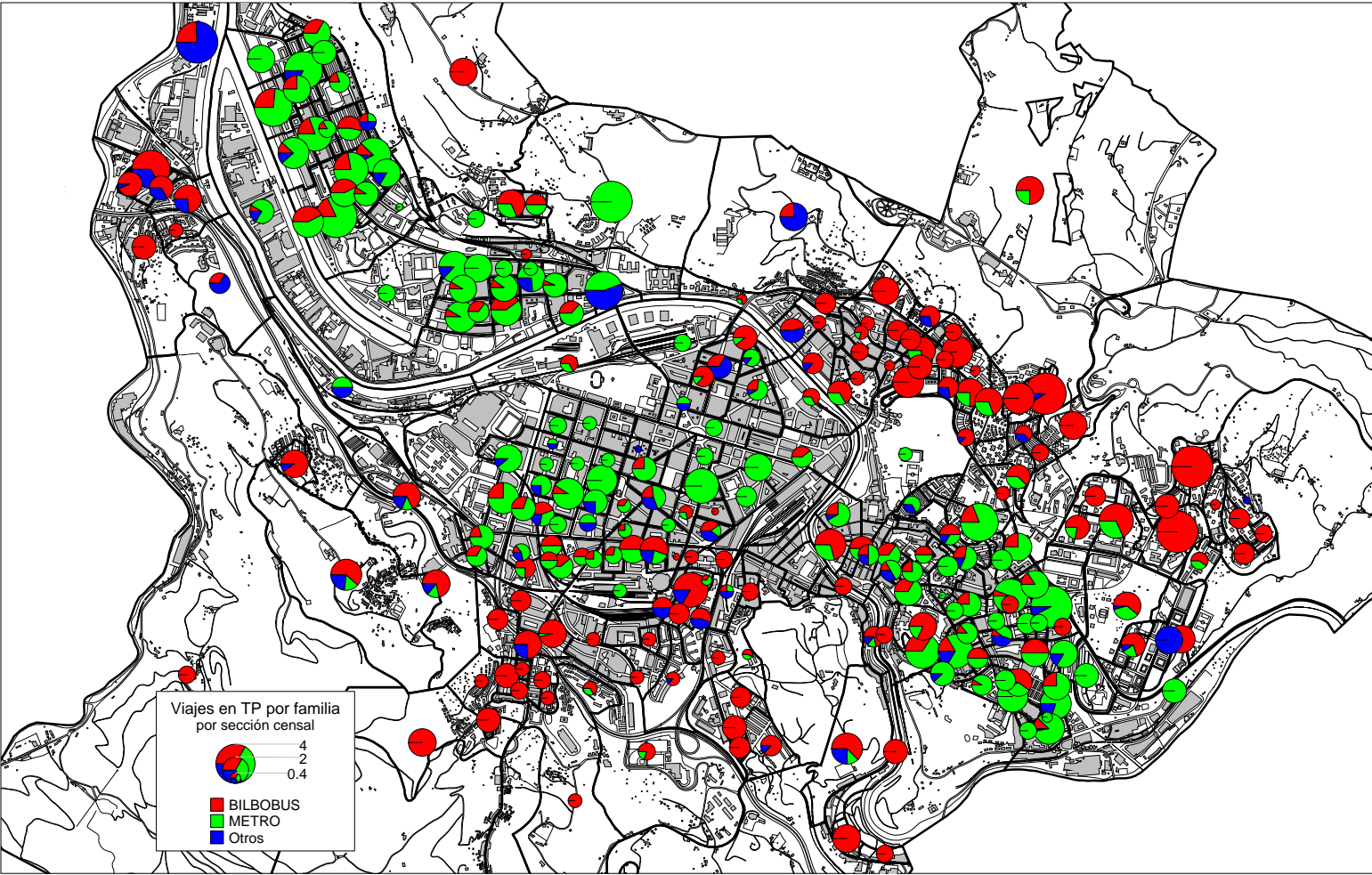
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View in downtown Bilbao:  
volumes, I/C, speeds...

# 4-Step Planning Model

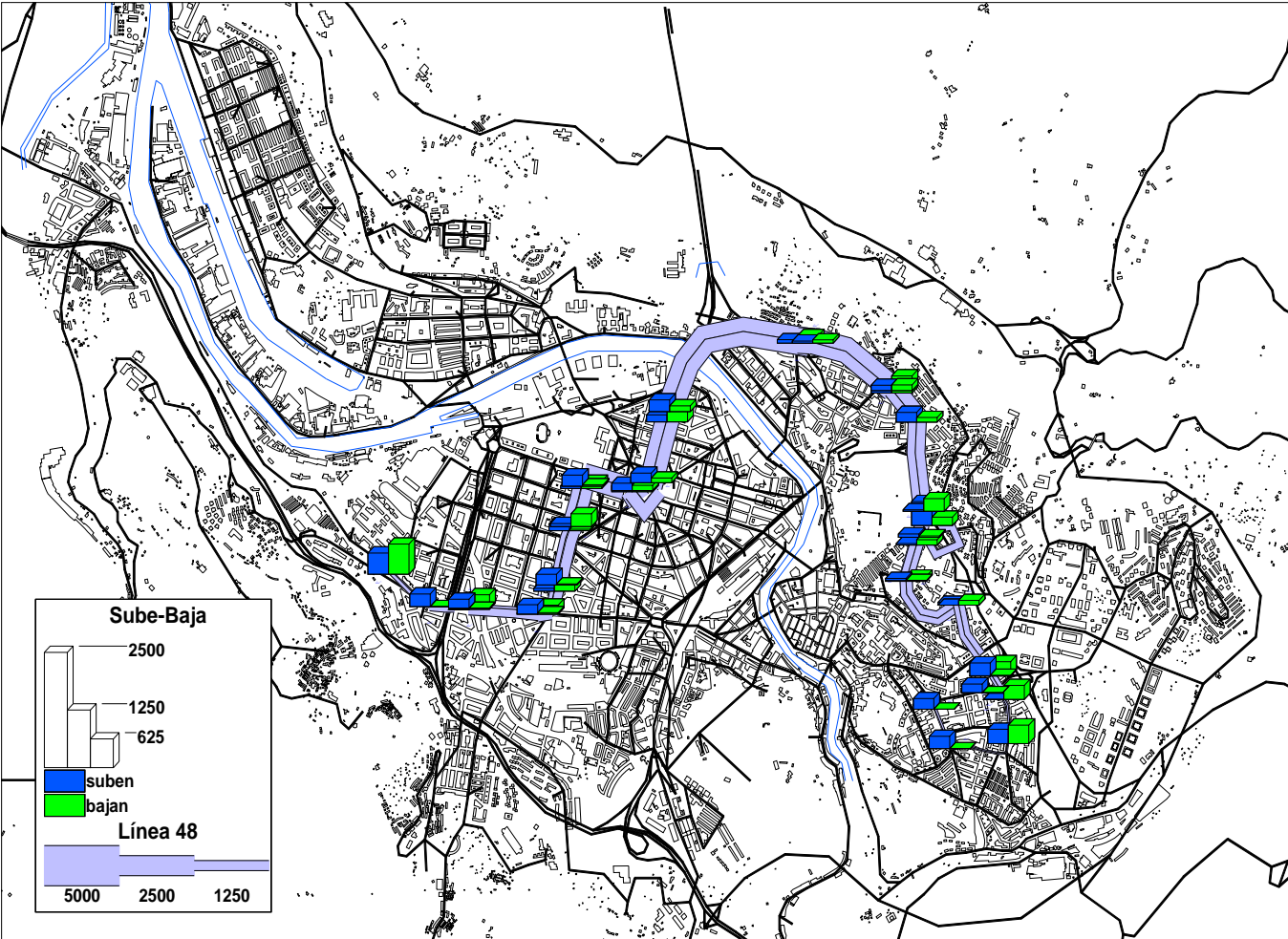
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# 4-Step Planning Model

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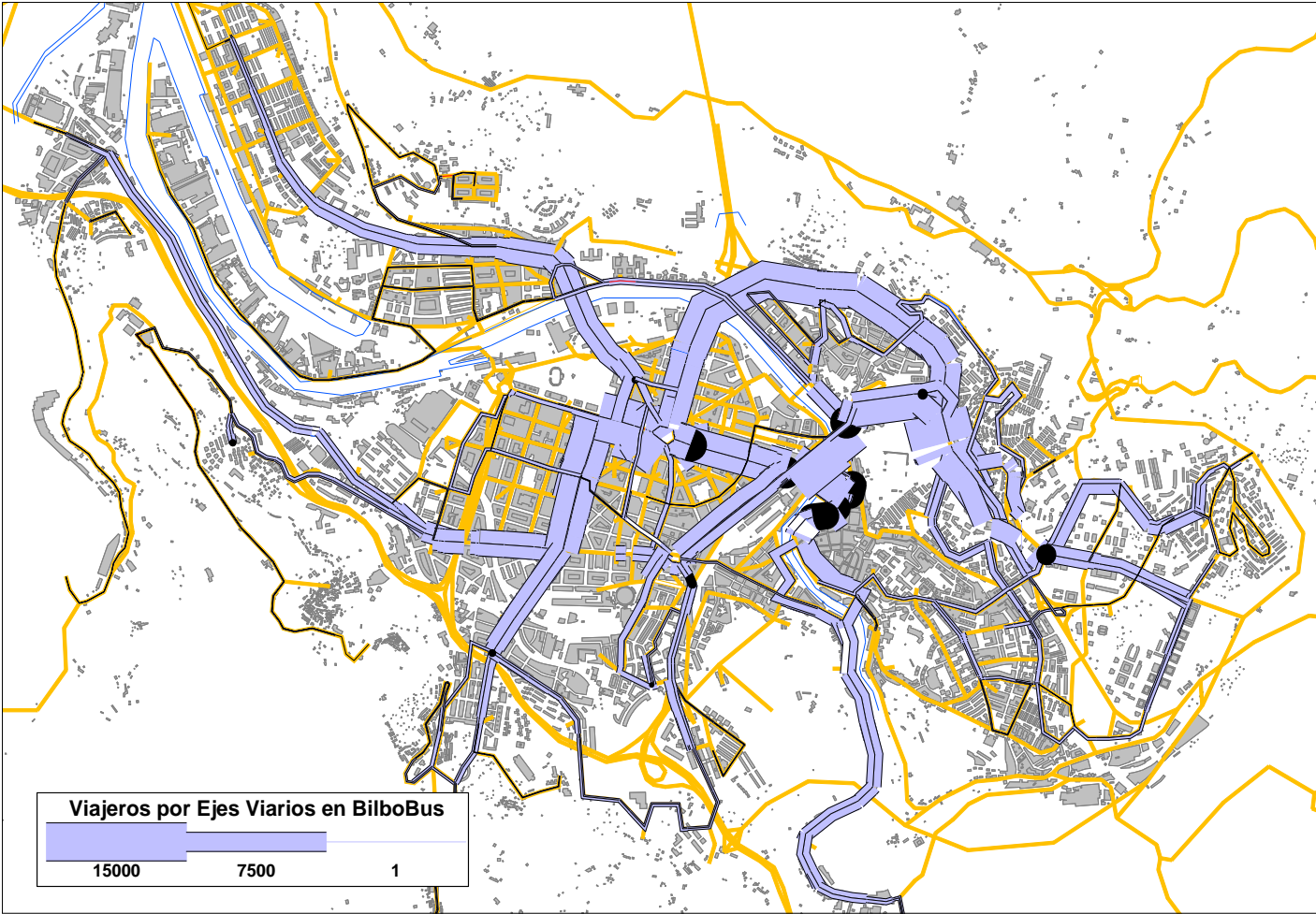


On-off counts per bus stop for all routes



# 4-Step Planning Model

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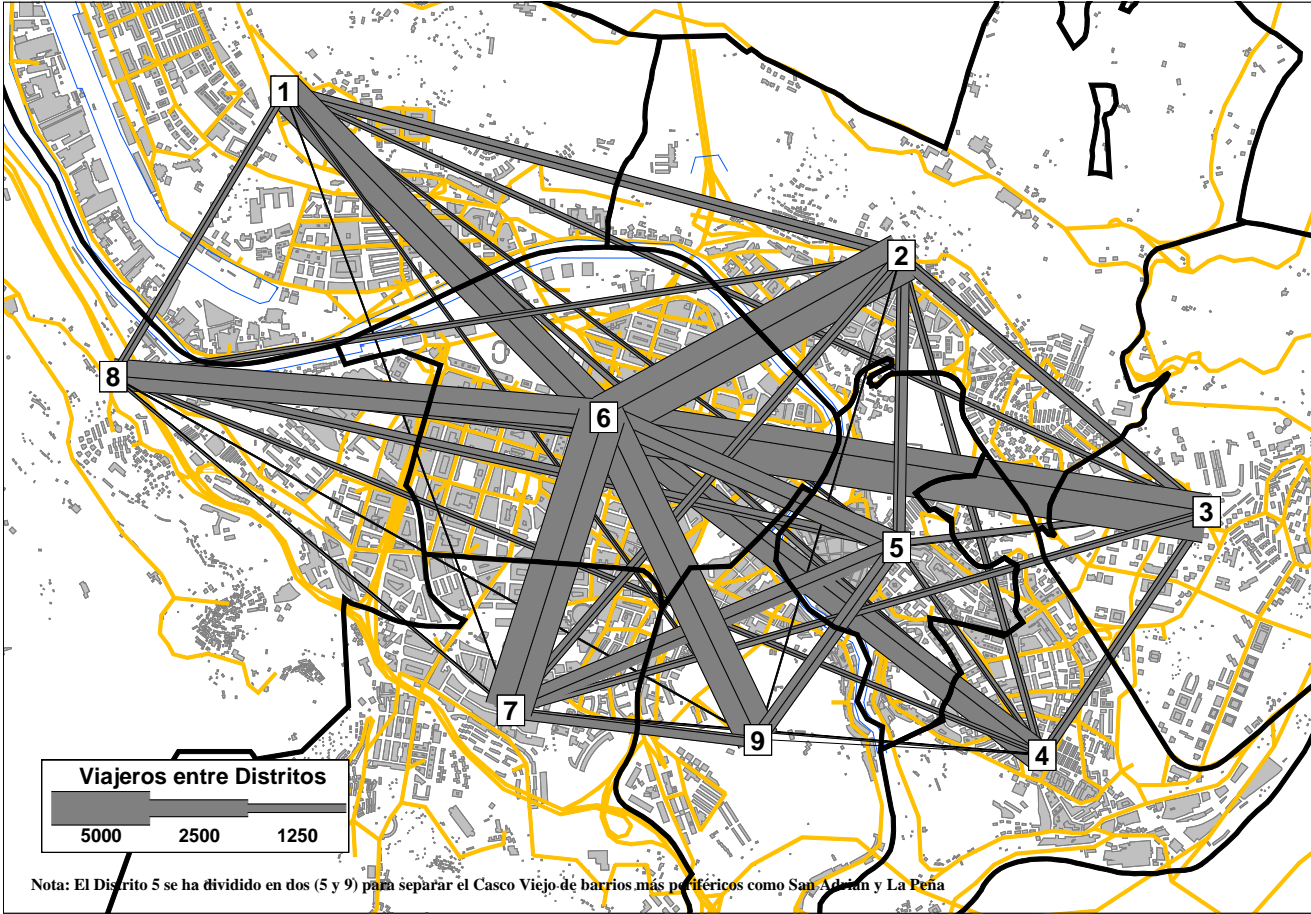


Aggregated bus flows along corridors



# 4-Step Planning Model

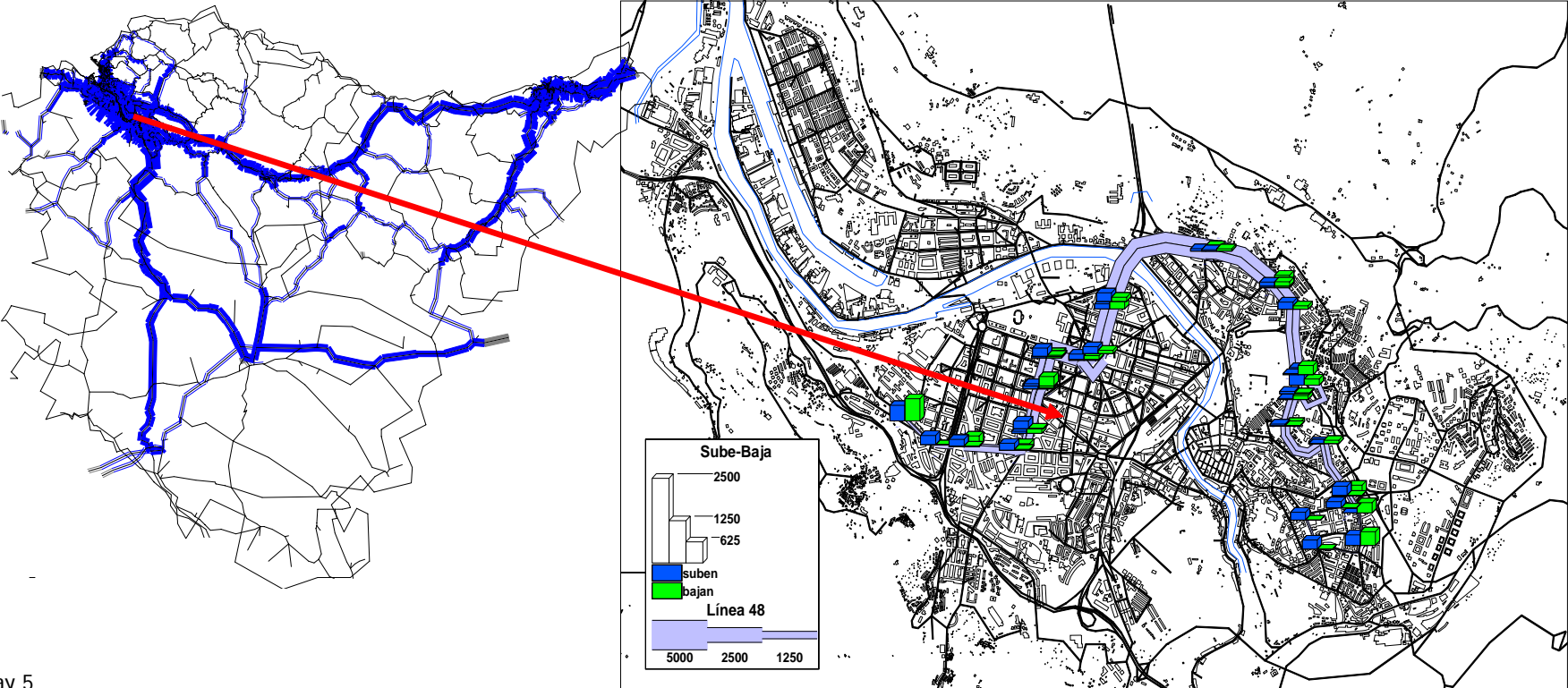
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# 4-Step Planning Model

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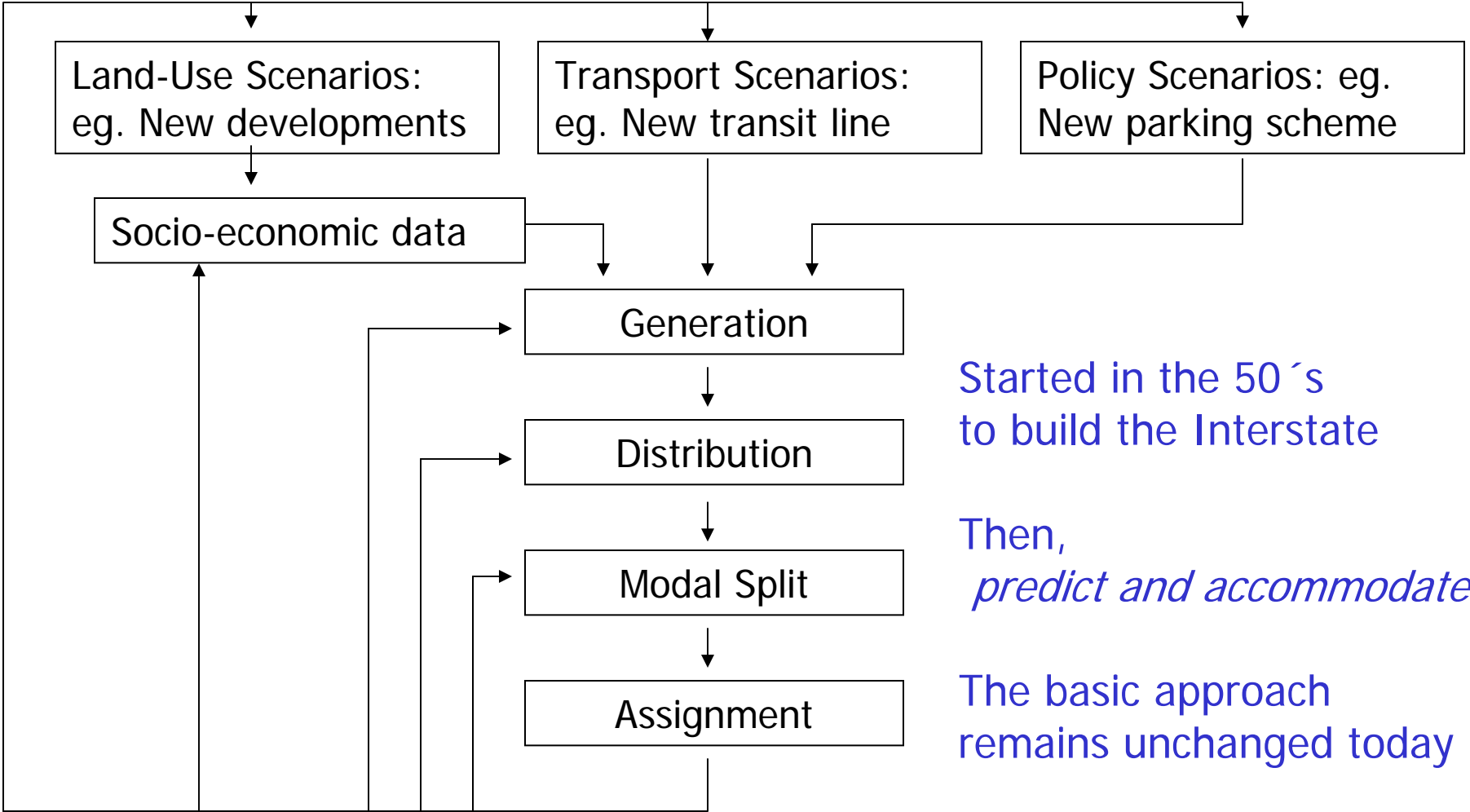
In a nutshell: every settlement, every dwelling, job center, road, no of lanes, posted speeds, signals, transit lines, stops, headways, commercial speeds...





# 4-Step Planning Model

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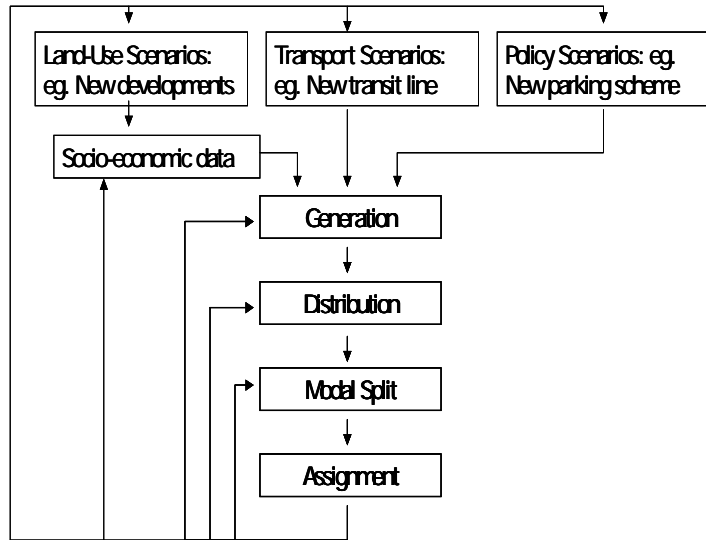
Started in the 50's  
to build the Interstate

Then,  
*predict and accommodate*

The basic approach  
remains unchanged today

# Why planning models are important?

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- Forecasts numbers can be easily used to kill a project or to keep it alive, even if it has no real merits
- Models often used as “black boxes”
- They can be easily manipulated to produce results fitting client’s wishes
- As few post-mortems are conducted, many are happy to predict the future



# Use of Planning models

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- Traditionally:
  - Demand estimates per mode
  - Explore future alternative land use-transport scenarios
- More and more:
  - Short term policies: Detours, parking policies, street closings, modal split ...
  - Environmental impacts
  - Impacts of ITS technologies
  - Operational studies for “non-regular” days
- Adapting to today’s needs: congestion & demand management, plus, air-quality issues



# The 4-Step Model

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- Commercial packages:
  - Trips
  - Emme2
  - Tranplan
  - QRSII
  - MinUTP
  - Tp+
  - Vissum
  - TransCad
  - .....
- From black boxes to script languages with open subroutines
- User-friendliness versus flexibility to model *your own thing*
- Bugs galore -> Direct link with programmers

“When using mathematics in modeling, if one cannot interpret the outcome in good, plain English then the paper should be burnt and one should start again”

Alfred Marshal, 19<sup>th</sup> century UK economist

# The 4-Step Model

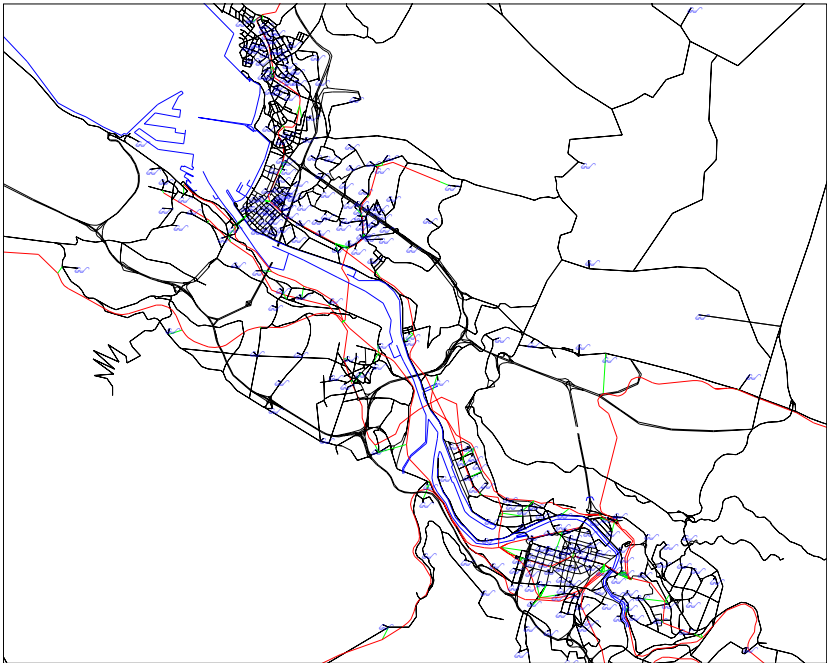
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- ***I don't believe in models!***
- ... but everyone has a model in his mind
- Modeling just a mental abstraction
- Don't be afraid to model a particular behavior, even if it is not in the books
- Models (and simulations) may become self-educating tools

# The 4-Step Model

## ■ Basic questions:



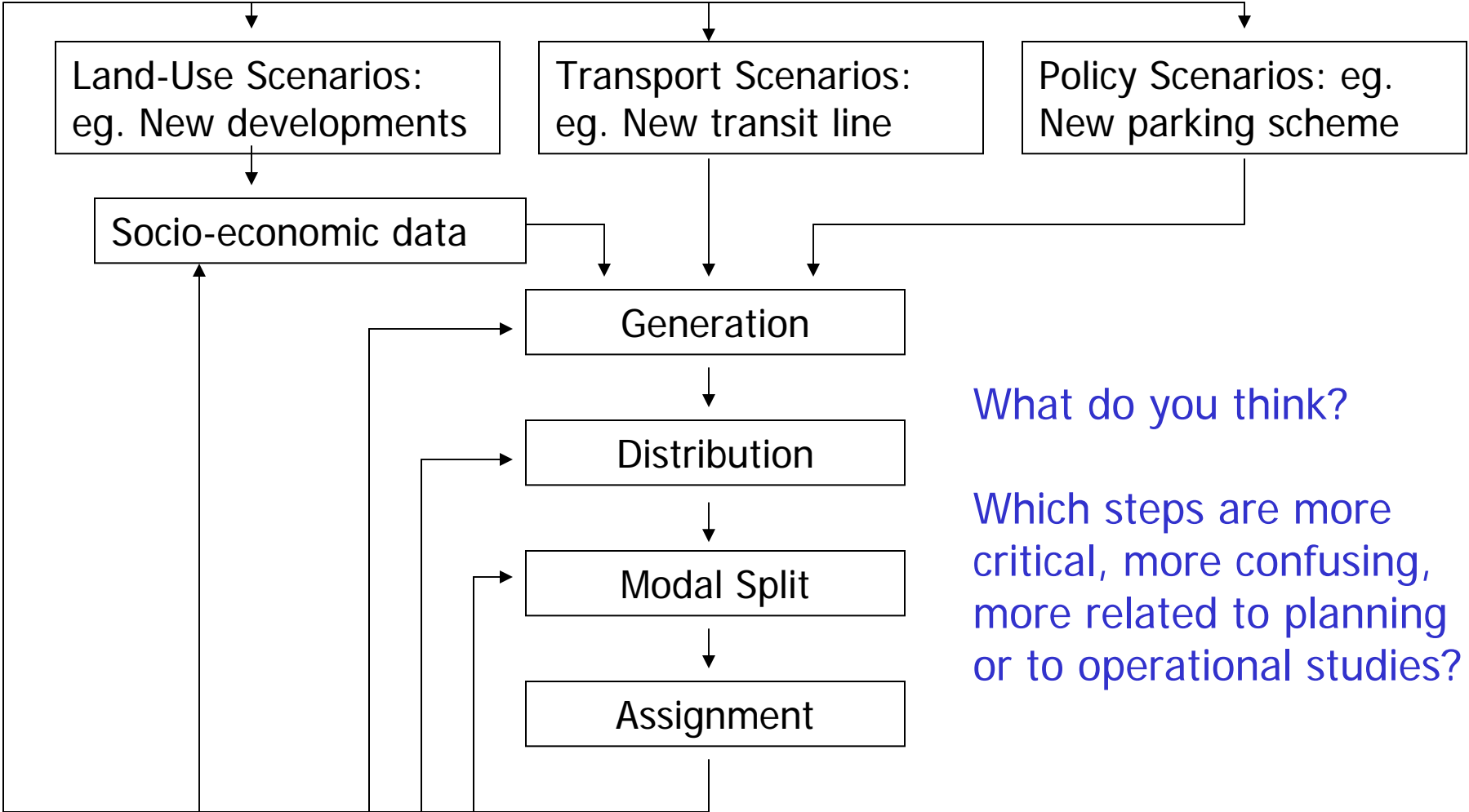
- Modeling objective
- Area to be modeled
- Level of detail
- Availability and quality of data
- Trip purposes to be represented
- Transport modes to include
- Treatment of heavy vehicles
- .....

## ■ How do you avoid GI-GO?



# The 4-Step Planning Model

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What do you think?

Which steps are more critical, more confusing, more related to planning or to operational studies?

# The 4-Step Model: Generation

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- Generation:
  - How many trips per family?<sup>1</sup>
  - Surveys to establish:
    - No of trips as a function of number of people per household, of number of cars, type of dwelling, residential area...
    - Distribution among trip purposes
    - Distribution between motorized and non-motorized
    - Distribution between chained and un-chained trips
    - Number of captive public transport users: e.g.: *f (No of people per household vs no of automobiles in household)*

<sup>1</sup> Number of trips per person a quasi-constant

# The 4-Step Model: Generation

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- Most important parameter: Number of members per dwelling unit
  
- Is trip generation sensitive to policy changes?:
  - The total number of trips or just those at a given time?
  - Or perhaps, just the trips made on a given mode?
  
- Trip purposes: HBW, HBO and NHB



# The 4-Step Model: Generation

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- Generation: How many trips per family?

Car trips in Bilbao				
No of People Per family	No of cars per family			
	0	1	2	3
1	0.1	1.2		
2	0.2	1.4	2.5	
3	0.4	1.6	2.6	3.3
4	0.6	1.8	3.3	4.1

# The 4-Step Model: Distribution

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- Where will the generated trips go to?  
Generation  $\leftrightarrow$  Attraction (jobs, shops, schools, residences...)
- Travel impedance as a restraint:
  - Travel impedance elements: time, distance, tolls, ramps, scenic value...
  - Friction curves:  $f$  (time, distance, tolls...)
  - Gravity model:  $T_{ij} = k (P_i * A_j) / I_{frict}$

# The 4-Step Model: Distribution

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- Where will the generated trips go to?
  - Internal vs External trips
  - Do impedance function hold in time?
  - Other origin-destination (o-d) matrices:
    - From road counts
    - From years past
  - The Watts effect:
    - More refined input data

# The 4-Step Model: Distribution

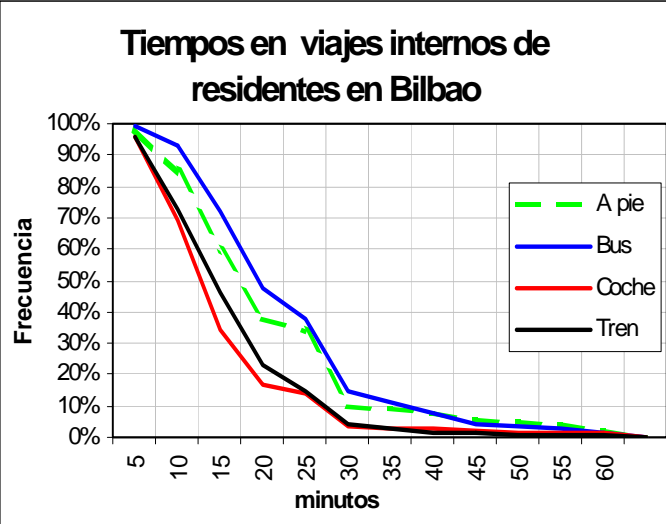
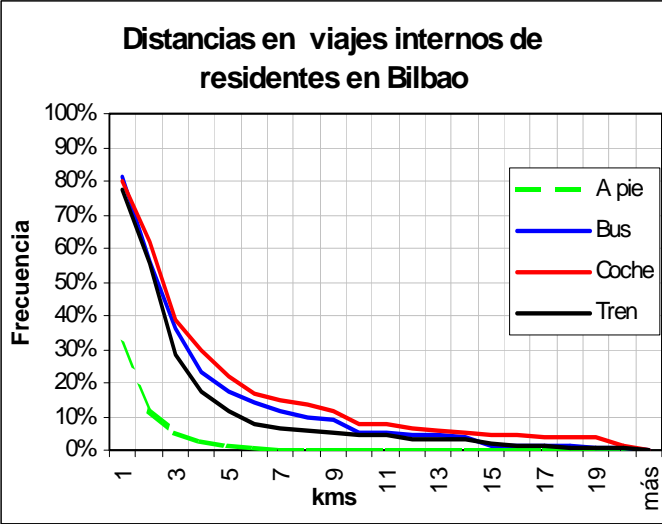
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- Where will the generated trips go to?
  - Internal vs External trips
  - Internal trips, those whose origin and destination are confined into a city limit
  - External trips, those whose destination is beyond city or town limits
  - Why is it important to differentiate them?

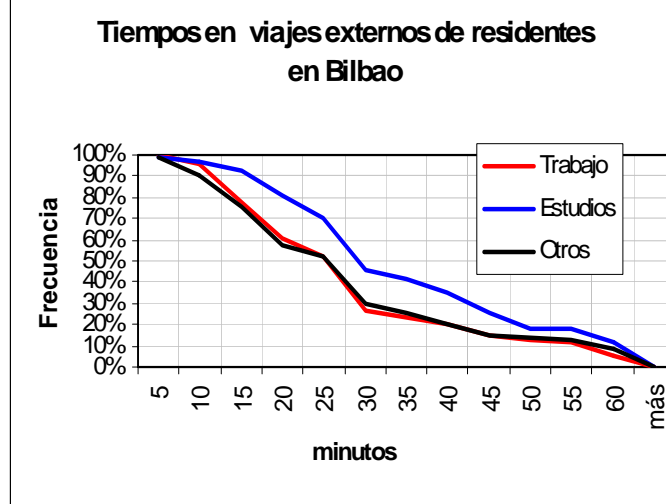
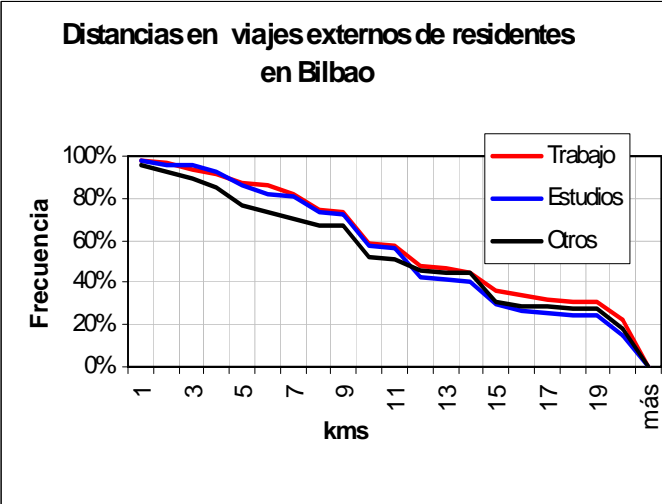


# The 4-Step Model: Distribution

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Internal trips



External trips

# The 4-Step Model: Modal Split

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- Modal Split: → Which transport mode will they choose? How do we divide the total o-d matrix?
  - Motorized vs Non-motorized trips
  - Motorized:
    - Automobile vs Transit
    - Automobile: drivers vs passengers
    - Transit: choice vs captive riders
  - Exceptions from the idealized analytical flow:
    - Captive riders case:
      - They are inelastic versus transit improvements
      - Their distribution stage is not necessarily the same as car drivers
        - Some destinations may become off-limits
    - Non-motorized trips: walk and bike trips



# The 4-Step Model: Modal Split

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- A Utility Function:
  - $U_i = a_i + b_i \cdot IVTT_i + c_i \cdot OVTT_i + d_i \cdot COST_i$
  - $a_i$  = modal constant
  - $b_i$  = In-Vehicle-Travel Time coefficient
  - $c_i$  = Out-Vehicle-Travel Time coefficient
  - $d_i$  = Cost (or ticket) coefficient

relationships among coefficients??

- For each modal option and for every o-d pair, there will be a utility function

# The 4-Step Model: Modal Split

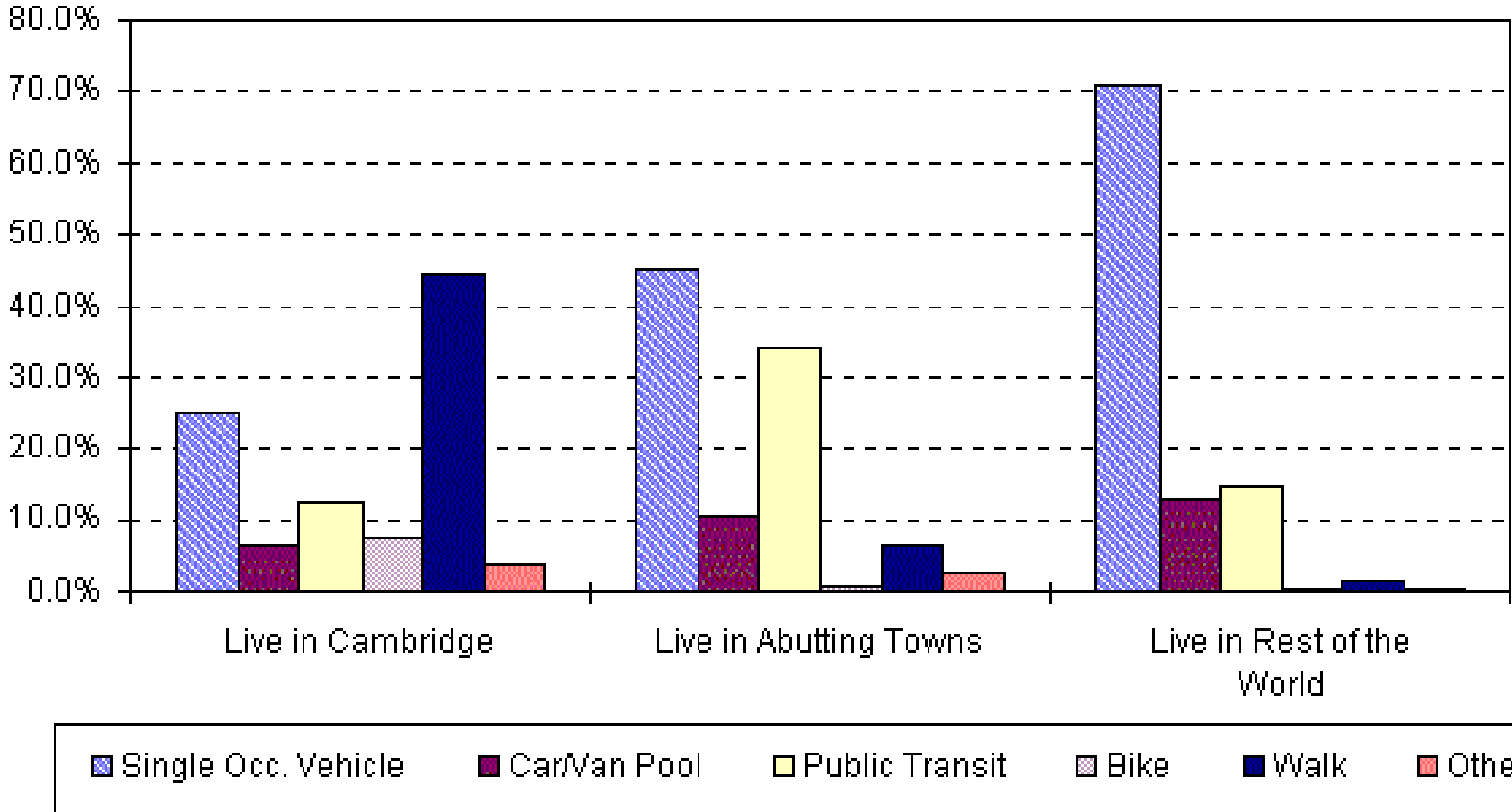
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- Modal Split:
  - Stated-Preferences: Revealed and Declared
  - Calibrated utility functions with weight factors: value of time<sup>1</sup>, penalty for waiting time...
  - *The modal constant*
  - Logit curves (or “S” curves):
    - $P(k) = e^{U_k} / \sum(e^{U_x})$
    - Sequential split or nested logit

# MIT The 4-Step Model: Modal Split

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### Cambridge Employees Means of Commuting



# The 4-Step Model: Assignment

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- *Assignment* → Which route will they take?
  - The shortest? The fastest? The least costly route? The more scenic route?
  - As more cars choose a route, what happens?
  - How do we represent mounting congestion?
  
- Analytical options:
  - All or Nothing (AOL) *Winner gets it all*
  - Capacity restraint *How to incorporate mounting congestion*
  - Equilibrium *A very rational universe out there*

# The 4-Step Model: Assignment

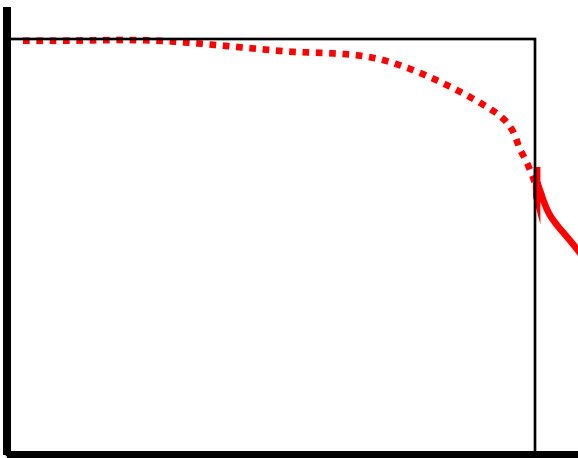
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- Assignment:
  - Critical pathing:
    - Capacity restraint
    - Equilibrium, etc.
  - ... *but we're dealing with human nature*
  - Volume-delay curves
  - V/C versus peak spreading
  - Tolls
  - Time segment of the O-D matrix to assign

# The 4-Step Model: Assignment

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- Volume-Delay curves – or how to represent growing congestion:
  - The BPR story: *Nothing like a good and simple formula to explain it all*



$$T_c = T_{ff} (1 + \alpha (i/C))^\beta$$

Even for intersection delay?

# The 4-Step Model: Assignment

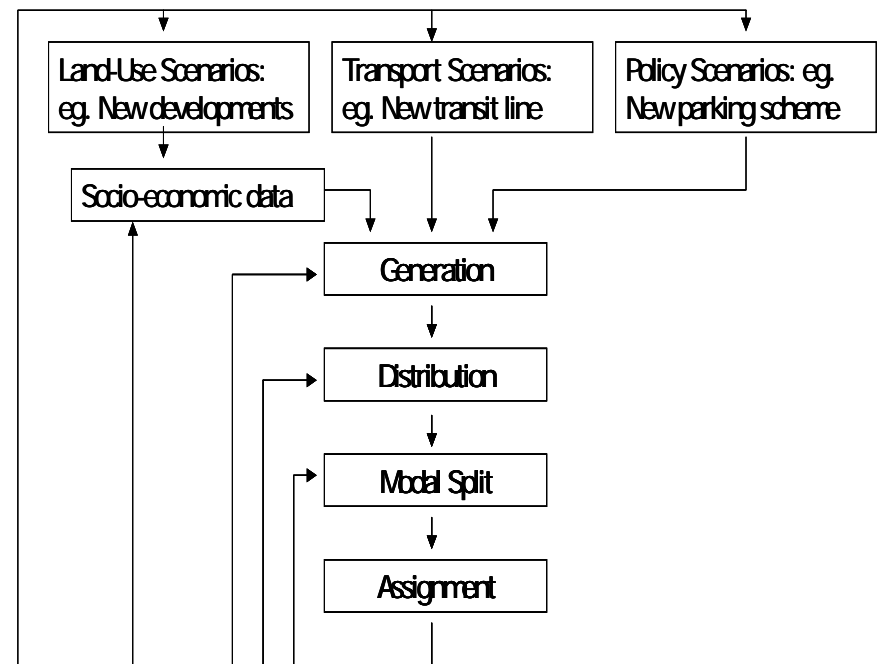
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- Assignment period:
  - 24 hour assignment as ADT (Average Daily Traffic)
  - Morning and evening rush-hour, off-peak...
  - Time variations associated to each trip purpose

# MIT The 4-Step Model

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- Feedback Loops:
  - Speed vs Volumes
  - Transit vs Road
  - How far or how long?
  - Trip generation sensitive to ease of travel?
- Convergence criteria
- Coherence with basic scenarios





- To know more about the analytical process:
  - “Modelling Transport” by Ortuzar, J. de D. and Willumsen, L.G., John Wiley, NY, 3<sup>rd</sup> Edition, 2001
  - “Travel Estimation Techniques for Urban Planning” NCHRP Report 365, 1998
  - User manuals of most commercial packages

# Critique of the 4-step Method

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- A tool created for a different goal: new road infrastructure. Today, focus on system management
- Peak spreading, and, induced demand
- Trip substitution? Impact of Information technologies?
- Description of “average, ideal conditions”
- Forecasting: Do basic parameters remain constant?  
Backcasting?
- Underlying theme: Individual choices
- Areas needing more insight:
  - Automobile ownership models (basic variable)
  - Auto-occupancy (basic variable)
  - Goods transport, taxis, goods distribution...

# Questions to ask

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- As a user of 4-step models results, you could raise questions such as:
  - Right scale? Discretized enough?
  - Calibration?
  - Validation? *Backcasting before forecasting*
  - Sensitivity analyses of results?
  - Modes considered?
  - Is it sensitive to policies being discussed?

# Traffic Models

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- To verify and incorporate (and even feedback) the output from the 4-step planning model
- 4-Step model: a rather crude approximation of
  - road or urban streets capacity
  - Interaction, such as queues blocking an intersection
  - Traffic speed (and resulting impacts)

# Traffic Models

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- Highway Capacity Manual:
  - Hand-calculations → HCS
- Macroscopic Models:
  - Representation of Platoons
- Microscopic Models
  - Individual vehicles are analyzed

Data availability + Computer power

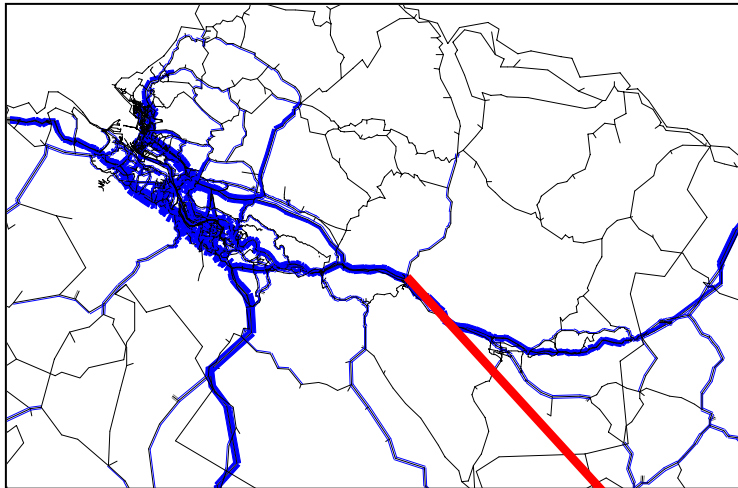
# Microscopic Traffic Models

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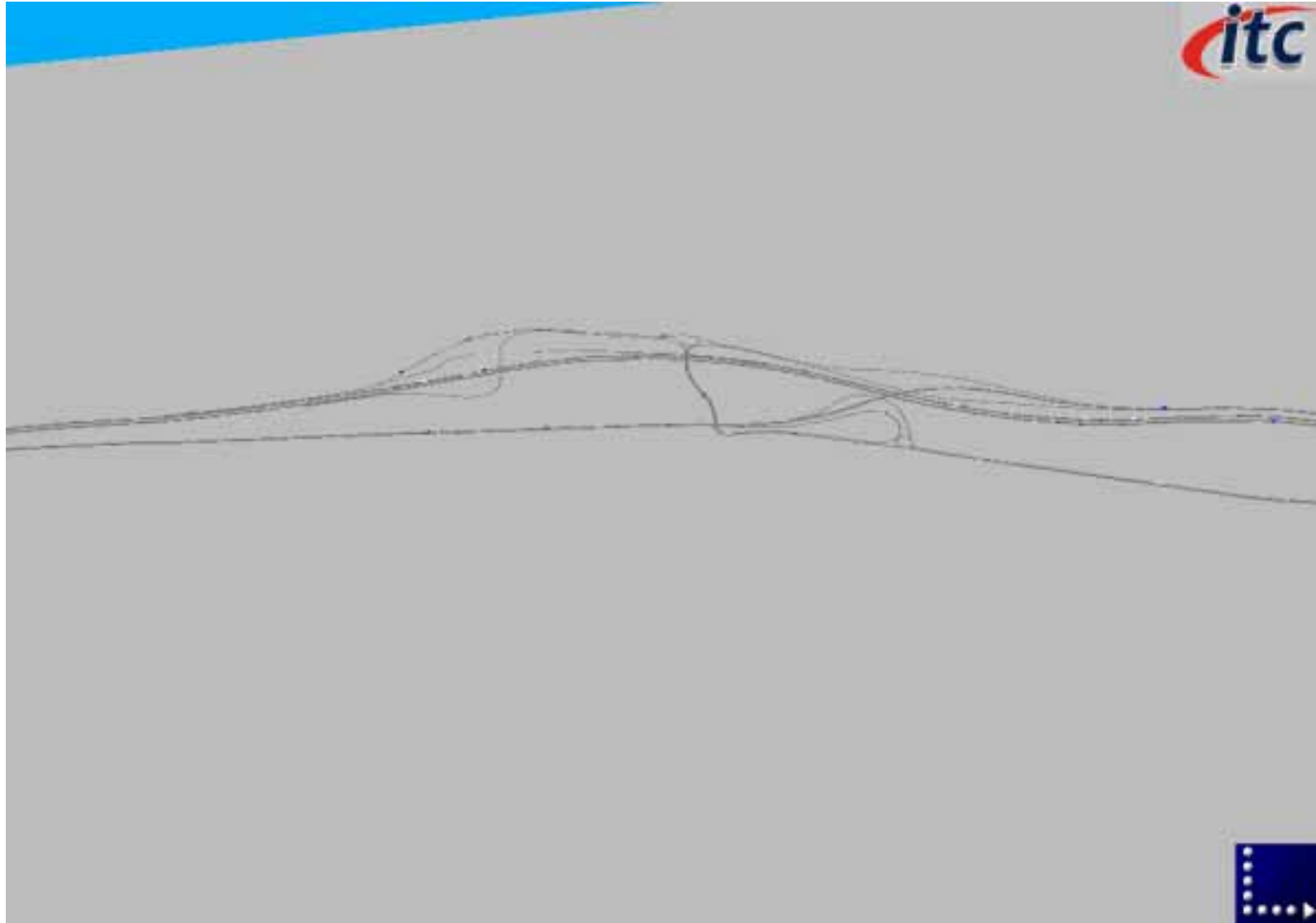
- From research tools (MITSIM for the Big Dig) towards daily practice
- Commercial packages:
  - CORSIM – Traf-Netsim
  - WATSim
  - Paramics
  - VISSIM
  - Aimsun2
  - .....

# Microscopic Traffic Models

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# Microscopic Traffic Models





# Microscopic Traffic Models

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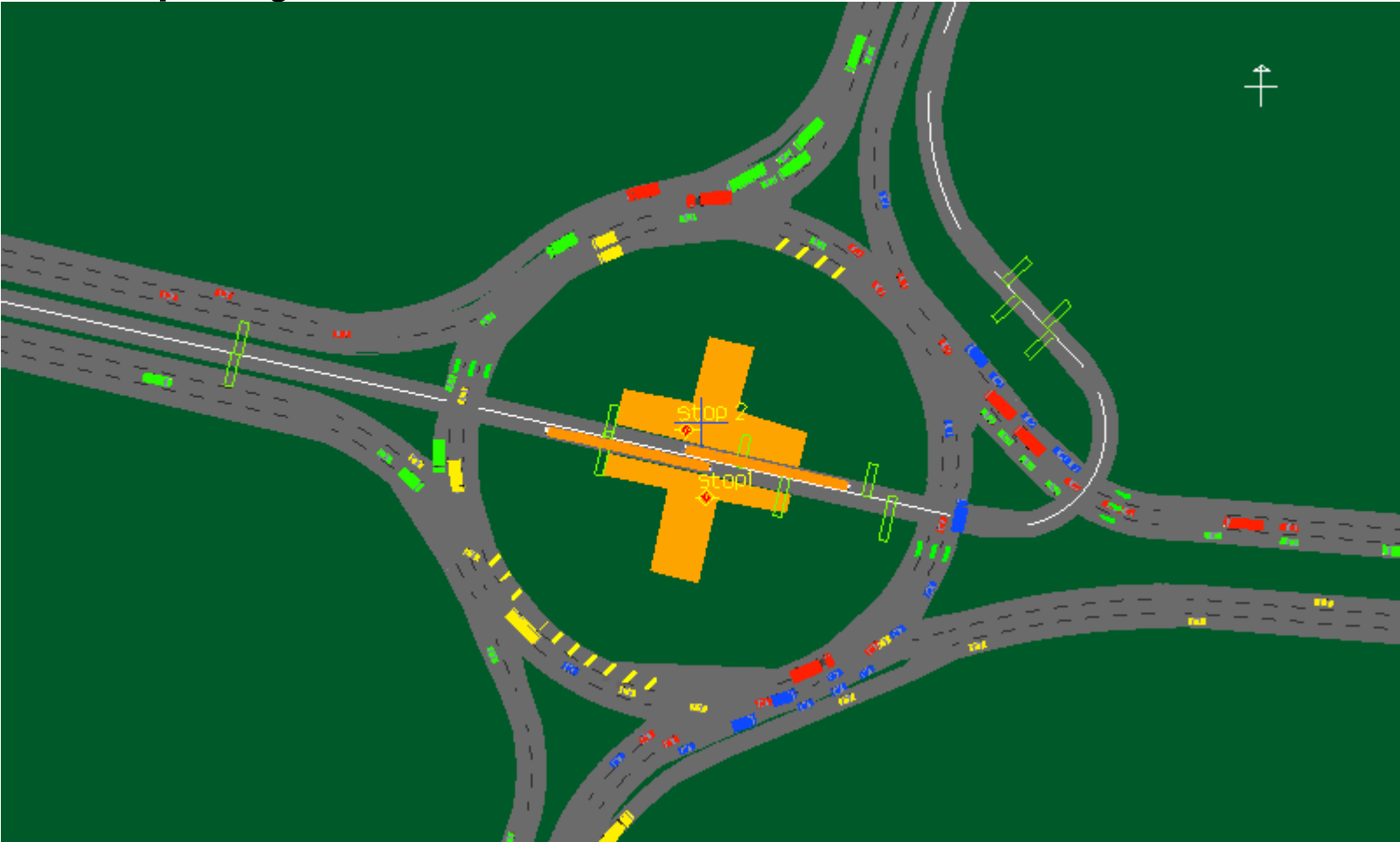
Used as well for environmental impact studies



# Microscopic Traffic Models

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Equally suited for transit...



# Integration of the Analytical Chain

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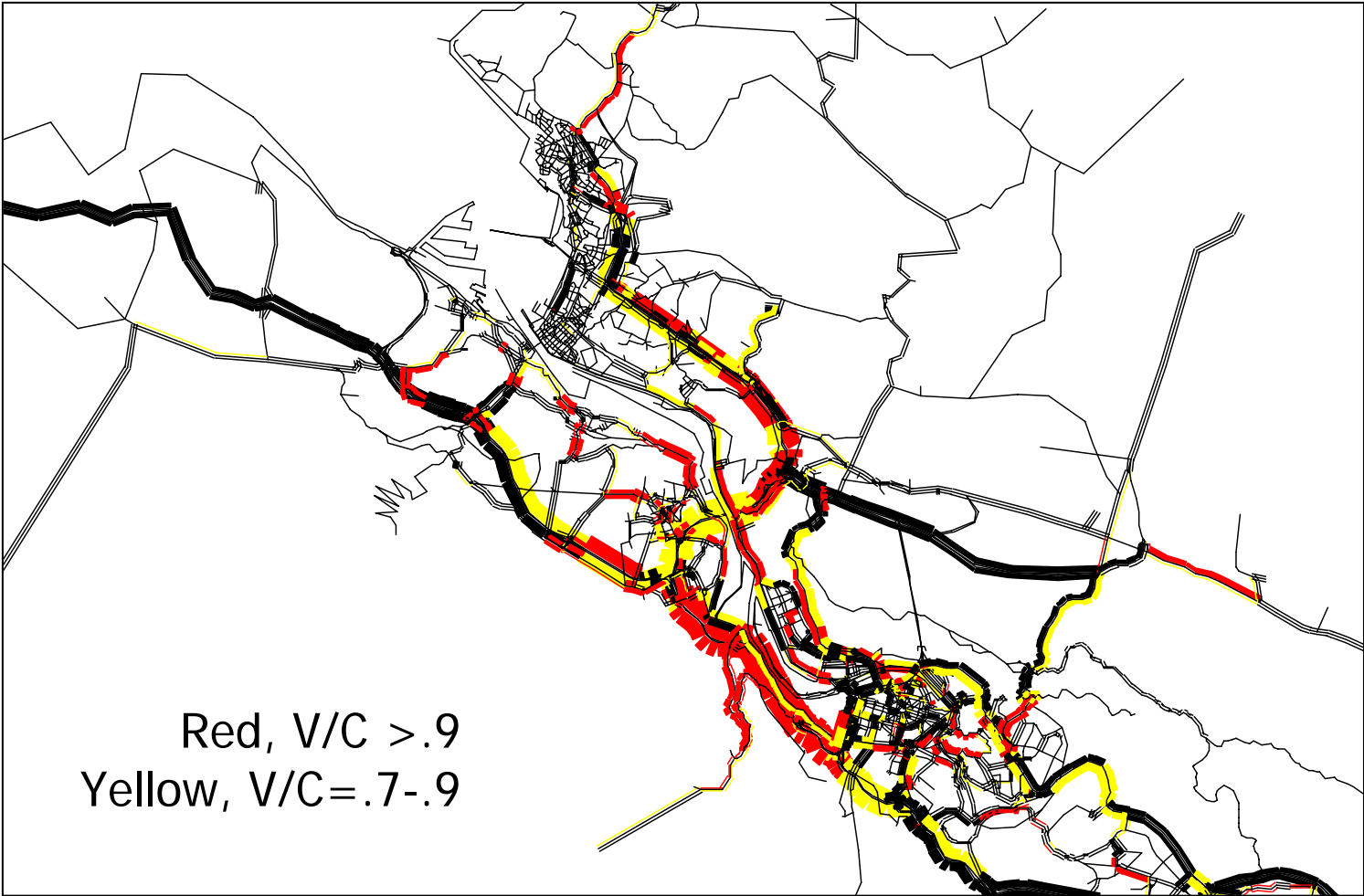
- An automatic chain of events
- Sequence:
  - GIS → Planning Model → Traffic Models → GIS → Postprocessors (environmental studies)
  - Or any combination of the above
- Critical analysis and judgement at every stage

- Operational Studies: *Life under congestion*
  - The higher the saturation, the higher the probability of an incident
  - The higher the saturation, the longer it will take to bring the system back to normal conditions, after an incident
  - But the 4-step planning model describes average un-eventful days out there!

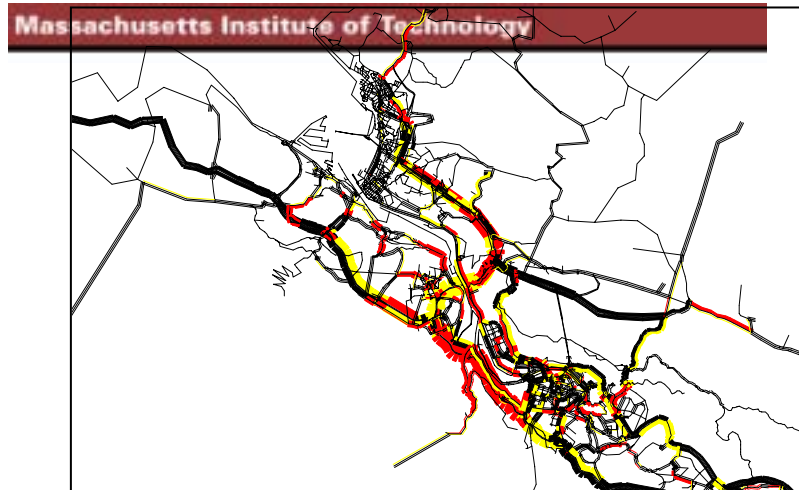
- Operational Studies: *Life under congestion*
  - From real-time vehicle counts to refined o-d matrices for incident management
  - Drivers with better information: Does the system behave differently?
  - What role for Intelligent Transport Systems? Tactical tools or strategic approaches?

# The 4-step planning model results

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# Planning vs Operational Studies



- *Not all red colors are created equal*
- The planning red: proximity to capacity
- The field red: actual operational instabilities
- The challenge is how to predict their relationship and take them into account for planning purposes

# IDAS: A new analytical approach

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- Developed in the Oak Ridge National Lab and the FHWA in USA – by Cambridge Systematics
- The pioneering work by Mitretek in Seattle, WA
- Goal: To be able to deploy ITS **more on fact than on faith**



- Operational Studies: *Life under congestion*
  - The IDAS approach
    - How do we measure ITS costs and benefits?
    - Should we incorporate ITS into standard planning procedures?
    - Or, should we resign ourselves to see ITS tools as a last minute tactical solution to be implemented by *practical men*, not planners?

# IDAS: A new analytical approach

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- It starts from the results of traditional 4-step planning packages
- It attempts to reproduce some of the algorithms contained in conventional planning packages
- Its essence is an evolving database on ITS costs and benefits
- It focuses on “problem days” not on the idyllic “average” days depicted by regular planning packages

# IDAS approach

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- IDAS as a new approach:
  - A must to analyze future scenarios which show growing saturation, as:
    - Operational improvements become critical
    - Integrated planning AND operational policies become compulsory
    - Global indicators become essential
  - A unique approach to deal with the main threat:
    - Road incidents – a harsh everyday reality far away from the ideal “average” planning day

- From trip-based modeling towards an activity-based approach:
  - Travel decisions are activity based
  - Understanding activity behavior is fundamental, rather than travel behavior
  - Focus on household dynamics, spatial and temporal interrelationships between trips

- Activity-based approach:
  - Travel is derived from the demand for activity participation
  - Sequences of patterns of behavior
  - Scheduling of household activities in time and space
- TRANSIMS (Los Alamos National Lab):
  - The goal is to replace current transport paradigm
  - Already applied in Portland, Or (See Bowman and Ben-Akiva 1997 paper on “Activity-based forecasting”)

## The McNamara fallacy<sup>1</sup>:

- The first step is to measure whatever can be easily measured. This is **OK** as far as it goes
- The second step is to disregard that which can't be easily measured or to give it an arbitrary quantitative value. This is **artificial and misleading**
- The third step is to presume that what can't be measured easily really isn't important. This is **blindness**
- The fourth step is to say that what can't be easily measured really doesn't exist. This is **suicide**

<sup>1</sup> by Charles Handy "The Empty Raincoat"