

# MIT Transportation Planning and Modeling

Massachusetts Institute of Technology

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UPR-MIT Boston Encuentro

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## MIT Scope

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1  
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1. Introduction: Transportation and Planning
2. GIS
3. 4-Step Models
4. Traffic (and other) models
5. Visualization
6. Closing thoughts

## Introduction: Transportation

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**Transportation is a great field to be in!**

1 "... simplistic solutions are proposed with sublime assurance,  
2 as if the construction of some type of transportation used  
in another city, would suddenly solve all problems"

3 "And these large matters are discussed without any  
4 organized framework, without any consideration of goals,  
mostly without any data ..."

5 "It is almost as if people delight in having an area in which  
6 anybody can speculate because nobody knows anything"

Roger L. Creighton, Urban Transportation Planning, 1970

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Introduction:  
12 Planning Steps by Frederick Salvucci

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- |   |   |   |
|---|---|---|
| 1 | 1. Scan the environment, review history, identify trends, project future conditions | 7. Consider operation and maintenance of facilities, services |
| 2 | 2. Define problem(s)  | 8. Evaluate alternatives                                      |
| 3 | 3. Develop solution(s)  | 9. Choose course of action                                    |
| 4 | 4. Identify relevant actors, institutions, primary roles and interests              | 10. Build constituency, consolidate allies, convert enemies   |
| 5 | 5. Consider implementation  | 11. Implement   |
| 6 | 6. Predict outcomes, benefits, costs, impacts                                       | 12. Operate and maintain                                      |

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Introduction: *Dealing with chaos*

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1

- Prof. Joseph Sussman explains that transportation is a CLIOS system:

2

- **Complex:** Several subsystems with feedback loops – Prone to sub optimizations – Unpredictability in time and space

3

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- **Large Scale:** large spatial and time impacts - irreversibilities

5

- **Integrated:** Impacts among subsystems

6

- **Open System:** Political, social and economic consequences – often unintended

## Introduction: Ain't this engineering?

Massachusetts Institute of Technology

1

Ken Kruckemeyer will gladly explain to you that...

2

3

Many of you went into engineering most probably to deal with systems and machines, but NOT WITH PEOPLE!

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Right or wrong?

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## Introduction: Ain't this engineering?

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1 Ken Kruckemeyer will gladly explain to you that...

2 Many of you went into engineering most probably to deal with systems and  
3 machines, but NOT WITH PEOPLE!

4 Right or wrong?

5 People appear to behave:

6 Irrationally

Intuitively

Unpredictably

In a perfect chaotic fashion

.....

But, is there a **logic bubble??**

Can we model people's behavior??

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## Introduction: Number crunchers beware!

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1 As Prof. Nigel Wilson likes to quote, his  
2 fellow English essayist, Dr Samuel  
3 Johnson, wrote in the 18<sup>th</sup> century that ...

4 "It is wonderful when a calculation is made,  
5 how little the mind is actually employed in  
6 the discharge of any profession"

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## MIT Introduction: Planning and Modeling

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- Mostly everyone use modeling as an aid for planning. And, those who don't?
- **Today, a quick tour on models:**
  - To provoke you into learning more about them
  - To describe modeling as a chain composed at least by GIS, transport and traffic models
  - To encourage you to use these tools as a fascinating work in progress

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## MIT Introduction: Models

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- How many types??
  - 4-step demand models
  - Land-Use Transportation models
  - G.I.S.
  - Traffic models
  - Operation models
  - Air pollution levels
  - Noise impact models
  - .....

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# MIT Introduction: Models

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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

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# MIT Introduction: Modeling

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- What for?
  - To quantify Level-of-Service improvements
  - To estimate transit ridership under different scenarios:
    - L-O-S improvements
    - New urban developments
    - New parking policies
    - .....
- **To predict the future perhaps??**

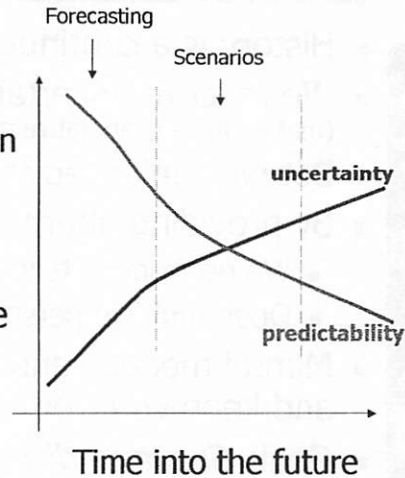
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## MIT Models and Forecasting...

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- 1 ■ Forecasting:
  - 2 ■ Short term extrapolation: The future on the basis of the past
  - 3 ■ Applicable to slow incremental change
  - 4 ■ The problem is that people believe that this situation will continue for ever
  - 5 ■ But...
  - 6



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## MIT ...And Scenarios

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- 1 ■ A conceptual description of the future based on cause and effect
- 2 ■ Invent and analyze **several stories** of equally plausible futures to bring forward surprises and unexpected leaps of understanding
- 3
- 4 ■ Goal is not to create a future, nor to choose the most probable one, but **to make strategic decisions that will be sound (or robust) under all plausible futures**
- 5
- 6

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## MIT | Scenarios: Why?

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- 1 ■ History is a continuum of *pattern breaks*
- 2 ■ We react to uncertainty thru denial  
(that is why a quantitative model is so reassuring!)
- 3 ■ But we can't predict the future with certainty
- 4 ■ By providing alternative images of the future:
  - We go from facts into perceptions, and,
  - Open multiple perspectives
- 5 ■ Mental models, and myths, control what you do  
and keep you from raising the *right* questions
- 6 ■ Goal: *Suspend disbelief in a story long enough to  
appreciate its potential impact*

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## MIT | Scenarios: How?

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- 1 ■ Examine the environment in which your  
actions will take place and see how  
those actions will fit in the prevailing  
forces, trends, attitudes and influences
- 2 ■ Identify driving forces and critical  
uncertainties
- 3 ■ Challenge prevailing mental modes
- 4 ■ Rehearse the implications

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## MIT | Scenarios: Rules

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- Goal:
  - 1 ■ Required decisions under each scenario? Vulnerabilities? Can we control the key driving forces?...
  - 2 ■ Good scenarios should be plausible, but also surprising by breaking old stereotypes
  - 3 ■ Do not assign probabilities to each alternative scenario
  - 4 ■ Assign a name to each scenario
  - 5 ■ A total of 3-4 scenarios: Not just two extremes plus a *probable* one. Good to have a wildcard
  - 6

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## MIT | Reading on Scenarios

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- 1 ■ "The Art of the Long View" by Peter Schwartz
- 2 ■ "Scenarios: The Art of Strategic Conversation" by Kees van der Heijden
- 3
- 4
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Both authors work for the Global Business Network ([www.gbn.org](http://www.gbn.org)) and come from the Shell Planning Group

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## Geographic Information Systems (G.I.S.)

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- GIS.
  - Digital mapping: *links with attributes*
  - Data management: *how many park-meters?*
  - Data analysis: *aggregate or disaggregate*
  - Data presentation: *graphical pie charts*
- Some commercial packages:
  - ArcInfo
  - ArcView
  - MapInfo
  - TransCad – GIS-T
  - .....

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## Geographic Information Systems (G.I.S.)

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- Integration of 3 technologies:
  - A graphical user interface (GUI)
  - A database management system (DBMS)
  - Spatial modeling tools
- Example: From road maps to Points of Interest (POI):
  - Up to 100 attributes per street
  - New "smart" roadmaps
  - [www.teleatlas.com](http://www.teleatlas.com)    [www.navtech.com](http://www.navtech.com)

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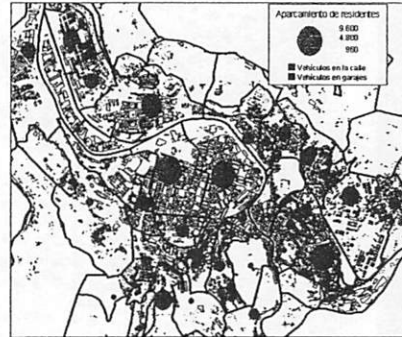


# Geographic Information Systems (G.I.S.)

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- Graphical databases to:
  - Analyze spatially available data (ie automobile ownership ratios, family sizes...)
  - Integrate data needed for transport modeling
  - Manage and process information
  - Post-process or to visualize results



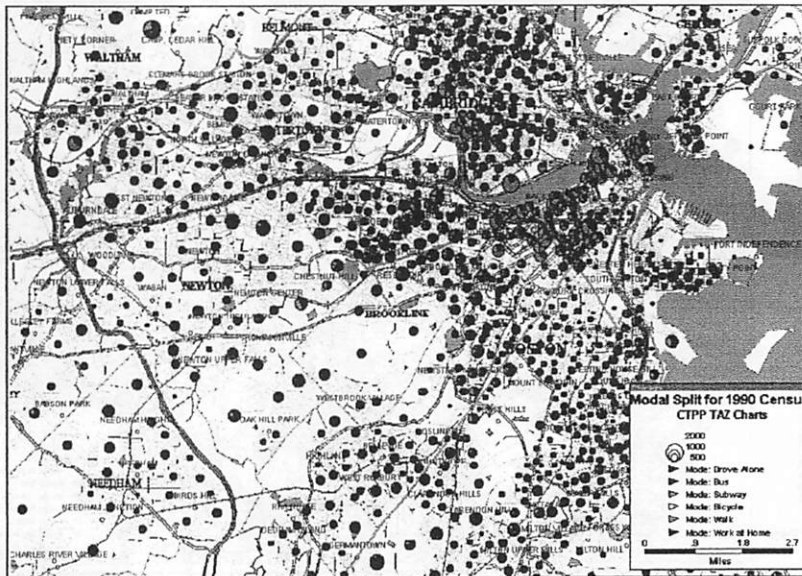
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# Green=Walk to Work, Blue= Transit, Red=Automobile... Boston

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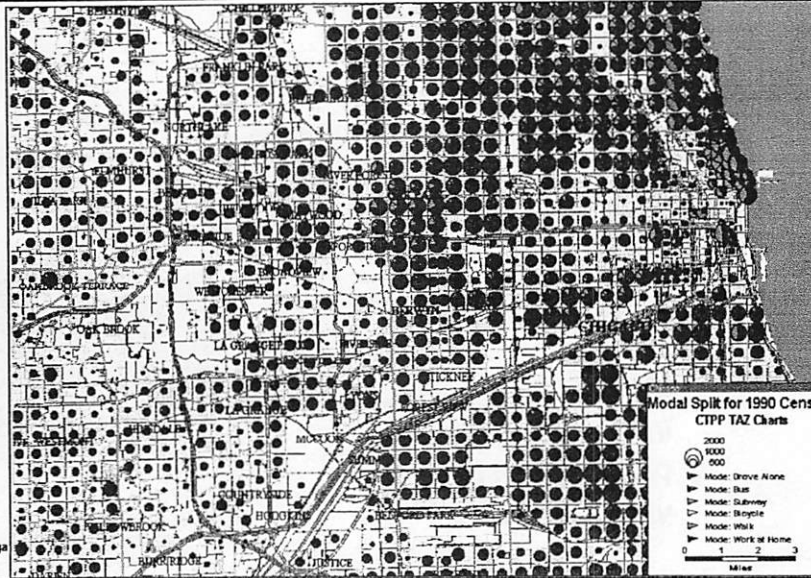
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### Green=Walk to Work, Blue= Transit, Red=Automobile... Chicago

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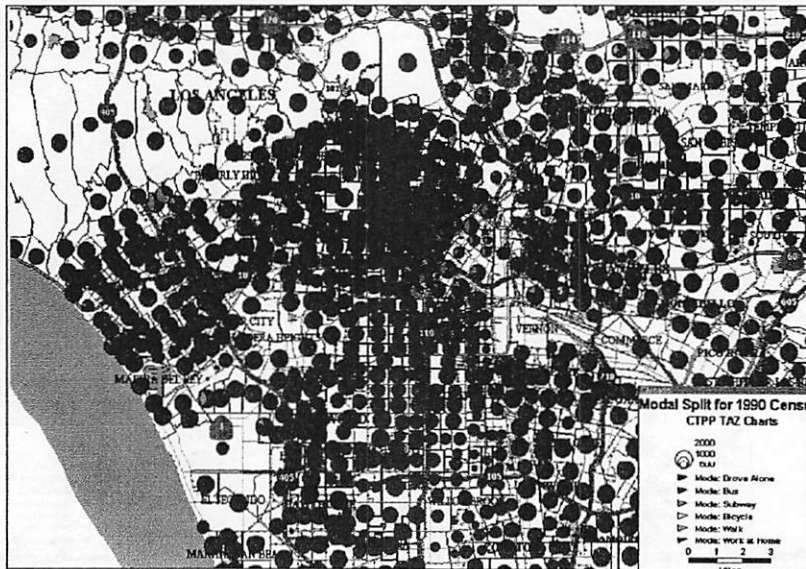
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### Green=Walk to Work, Blue= Transit, Red=Automobile... Los Angeles

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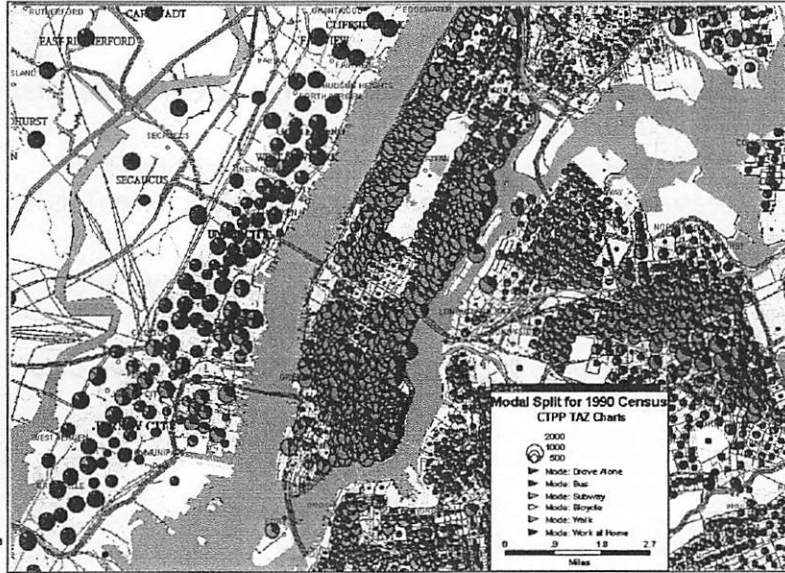
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# Green=Walk to Work, Blue= Transit, Red=Automobile... Manhattan

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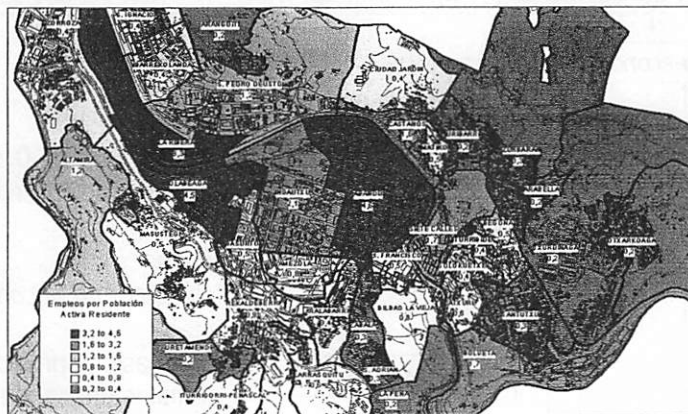


# Geographic Information Systems (G.I.S.)

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## How many residents, how many jobs, how many shops within the catchment area of a station?

- 1
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# MIT Dealing with Data...

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

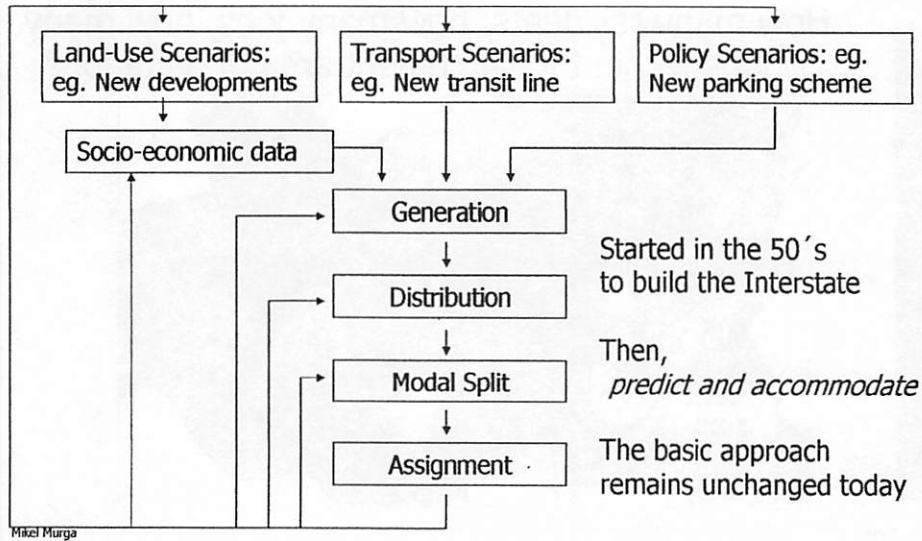
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- The first step is to measure whatever can be easily measured. This is **OK** as far as it goes
- The second step is to disregard that which can't be easily measured or to give it an arbitrary quantitative value. This is **artificial and misleading**
- 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"

# MIT 4-Step Planning Model

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# MIT Use of 4-Step models

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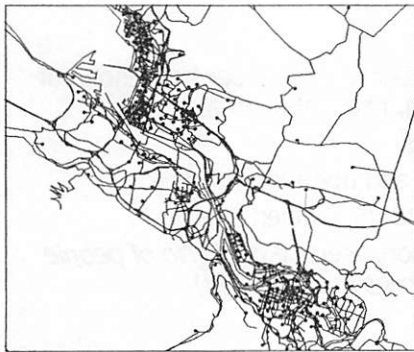
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- Traditionally:
  - Demand estimates per mode
  - Explore future alternative land use-transport scenarios
- More and more:
  - Short term policies: Detours, parking policies, street closings, modal split ...
  - Environmental impacts
  - Impacts of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

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# MIT The 4-Step Model

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- 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?

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# MIT The 4-Step Model Software

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- 1 ■ Commercial packages:
    - Trips
    - Emme2
  - 2 ■ Tranplan
  - 3 ■ QRSII
  - 4 ■ MinUTP
  - 5 ■ Tp+
  - 6 ■ Visum
  - 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"

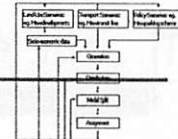
Alfred Marshal, 19<sup>th</sup> century UK economist

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# MIT The 4-Step Model: Generation

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## Generation:

- 1 ■ How many trips per family?<sup>1</sup>
- 2 ■ 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.:  $f(\text{No of people per household vs no of automobiles in household})$
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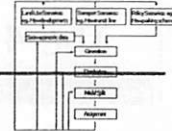
<sup>1</sup> Number of trips per person a quasi-constant

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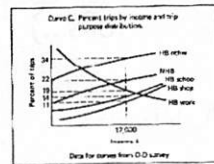
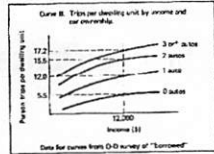
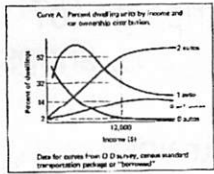
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# MIT The 4-Step Model: Generation

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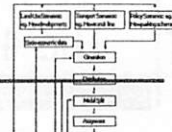


- Most important parameter: Number of members per dwelling unit
- Is trip generation sensitive to policy changes?
  - The total number of trips or just those at a given time?
  - Or perhaps, just the trips made on a given mode?
- Trip purposes: HBW, HBO and NHB

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# MIT The 4-Step Model: Generation

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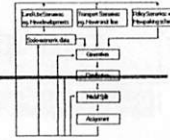


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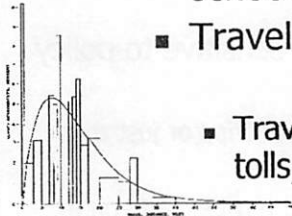
## Generation: How many trips per family?

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

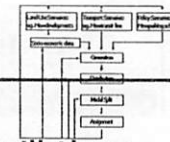
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- Where will the generated trips go to?  
Generation  $\leftrightarrow$  Attraction (jobs, shops, schools, residences...)



- Travel impedance as a restraint:
  - Travel impedance elements: time, distance, tolls, ramps, scenic value...
  - Friction curves:  $f$  (time, distance, tolls...)
  - Gravity model:  $T_{ij} = k (P_i * A_j) / I_{frict}$

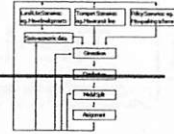


Modal Split:  $\rightarrow$  Which transport mode will they choose? How do we divide the total o-d matrix?

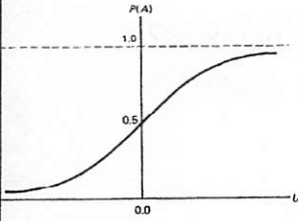
1. Motorized vs Non-motorized trips
2. Motorized:
  - Automobile vs Transit
  - Automobile: drivers vs passengers
  - Transit: choice vs captive riders
3. Exceptions from the idealized analytical flow:
  - Captive riders case:
    - They are inelastic versus transit improvements
    - Their distribution stage is not necessarily the same as car drivers
      - Some destinations may become off-limits
  - Non-motorized trips: walk and bike trips
- 4.
- 5.
- 6.

# MIT The 4-Step Model: Modal Split

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- 2
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- 4
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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

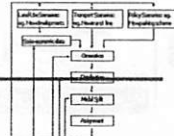
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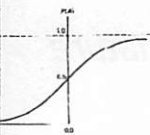
38 (muero)

# MIT 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

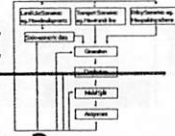
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## The 4-Step Model: Assignment

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Assignment → Which route will they take?

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- 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*

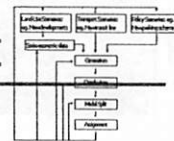
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## The 4-Step Model: Assignment

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- Assignment:

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

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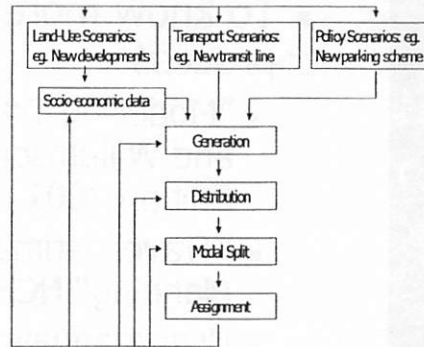
40 41

# MIT The 4-Step Model: Feedback loops

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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



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# MIT 4-Step models: Questions to ask

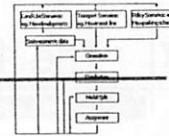
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- As a user of 4-step models results, you could raise questions such as:
  - Right scale? Discretized enough?
  - Calibration? —
  - Validation? *Backcasting before forecasting* *(go back 10 or x years) explore ridership*
  - Sensitivity analyses of results?
  - Modes considered?
  - Is it sensitive to policies being discussed?

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1

- To know more about the analytical process:

2

- "Modelling Transport" by Ortuzar, J. de D. and Willumsen, L.G., John Wiley, NY, 3<sup>rd</sup> Edition, 2001

3

- "Travel Estimation Techniques for Urban Planning" NCHRP Report 365, 1998

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- User manuals of most commercial packages

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Road flows in the Basque Country for a particular scenario

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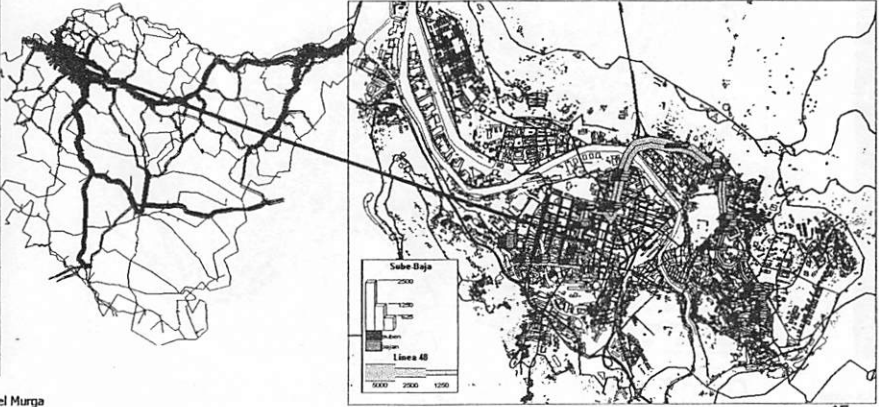
Bilbao

# MIT From GIS to 4-Step Planning Model

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**Data repository** for every settlement, every dwelling, job center, road, no of lanes, posted speeds, signals, transit lines, stops, headways, commercial speeds...

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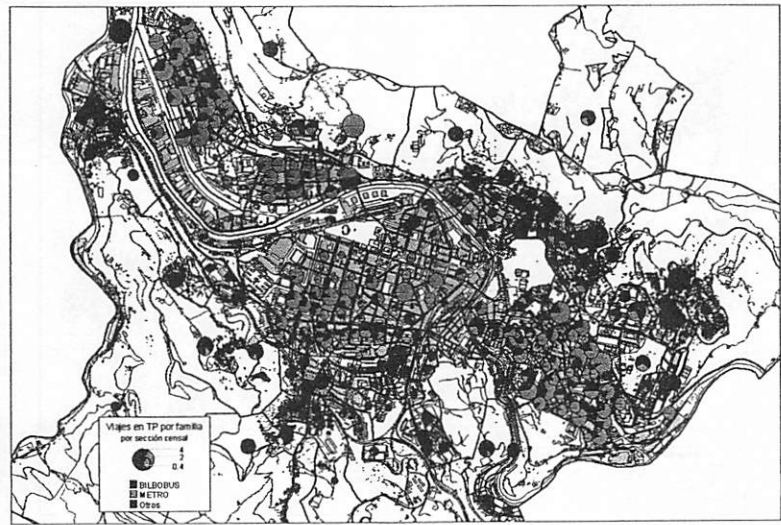
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# MIT 4-Step Model: Sample outputs

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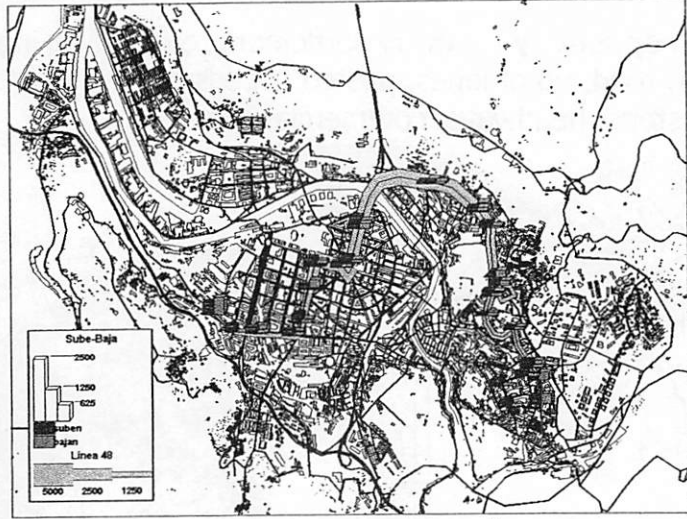
**Modal share among Subway, Buses and chartered buses.**



# 4-Step Model: Sample outputs

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On-off counts per bus stop for all routes

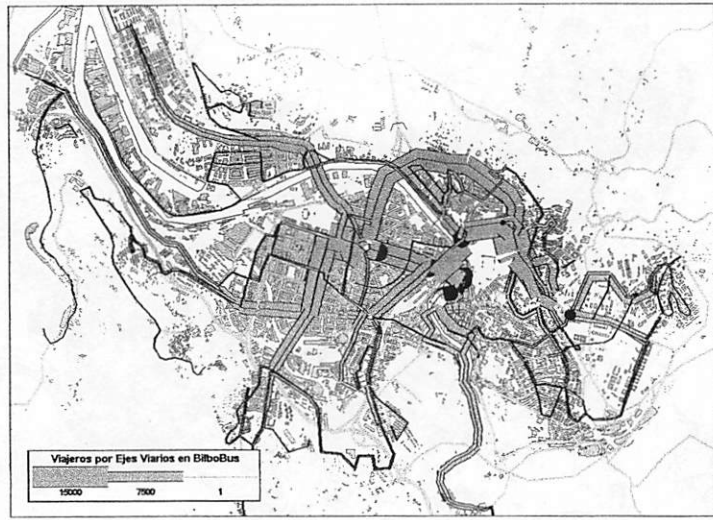
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# 4-Step Model: Sample outputs

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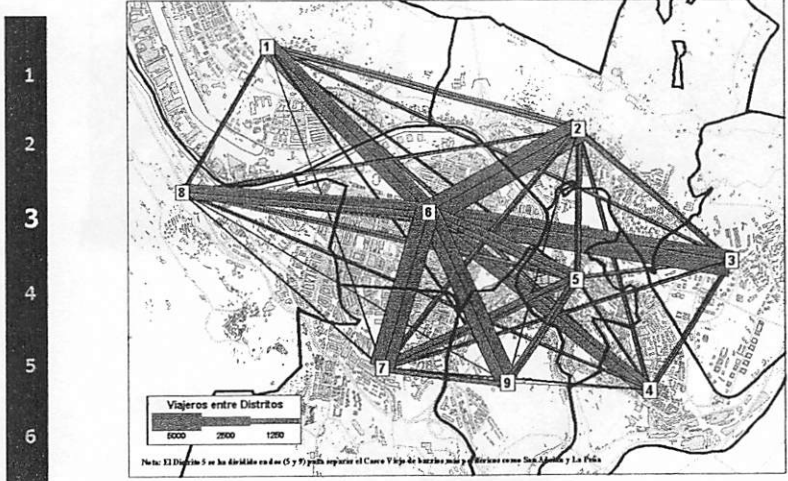
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Aggregated bus flows along corridors

48

# MIT 4-Step Model: Sample outputs

Massachusetts Institute of Technology

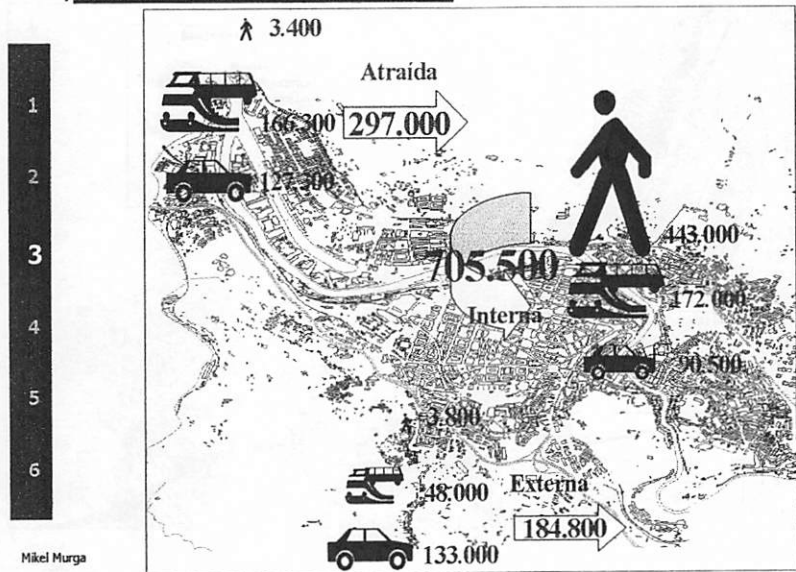


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The Overall View: A simplified O-D matrix

# MIT 4-Step Model: Sample outputs

Massachusetts Institute of Technology



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Diagnóstico  
2003 UPR-MIT Encuentro

## Assignment of pedestrian, transit and auto trips

MIT  
Massachusetts Institute of Technology

450.000 viajes a pie

456.000 viajes en TP

351.000 viajes en coche

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2003 UPR-MIT Encuentro

## The 4-step model describes final equilibrium... and new habits!

MIT  
Massachusetts Institute of Technology

**Red modelizada**  
Red viaria  
Costa y límites  
Líneas de BiboBus y Metro  
— Línea 10 (intervalo= 12 min.)  
— Metro (intervalo= 5min.)  
Paradas de BiboBus y Metro  
● Línea 10  
● Metro  
0 2 4 6  
Kilometers

— 10 San Ignacio - Arriaga

viajes anuales

Año	Viajes anuales
1995	~2,800,000
1996	~2,500,000
1997	~1,800,000
1998	~1,500,000
1999	~1,200,000
2000	~1,000,000

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52

- Operational Studies: *Life under congestion*
  - 1 ■ The higher the saturation, the higher the probability of an incident
  - 2 ■ The higher the saturation, the longer it will take to bring the system back to normal conditions, after an incident
  - 3
  - 4
  - 5 ■ But the 4-step planning model describes average un-eventful days out there!
  - 6

- Operational Studies: *Life under congestion*
  - 1 ■ From real-time vehicle counts to refined o-d matrices for incident management
  - 2 ■ Drivers with better information: Does the system behave differently?
  - 3 ■ What role for Intelligent Transport Systems? Tactical tools or strategic approaches?
  - 4
  - 5
  - 6

## 4-Step Models: New Trends

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1

- From trip-based modeling towards an activity-based approach:

2

- Travel decisions are activity based

3

- Understanding activity behavior is fundamental, rather than travel behavior

4

- Focus on household dynamics, spatial and temporal interrelationships between trips

5

6

## Traffic Models

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1

- To verify and incorporate the output from the 4-step planning model

2

- 4-Step model: a rather crude approximation of

3

- road or urban streets capacity

4

- Interaction, such as queues blocking an intersection

5

- Traffic speed (and resulting impacts)

6

## MIT Traffic Models

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1

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6

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

Data availability + Computer power

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## MIT Microscopic Traffic Models

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1

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

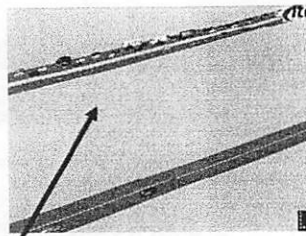
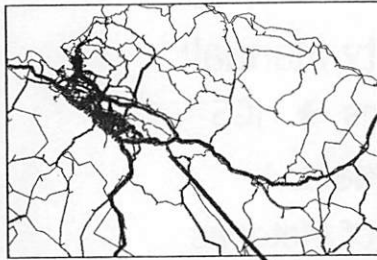
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# MIT Microscopic Traffic Models

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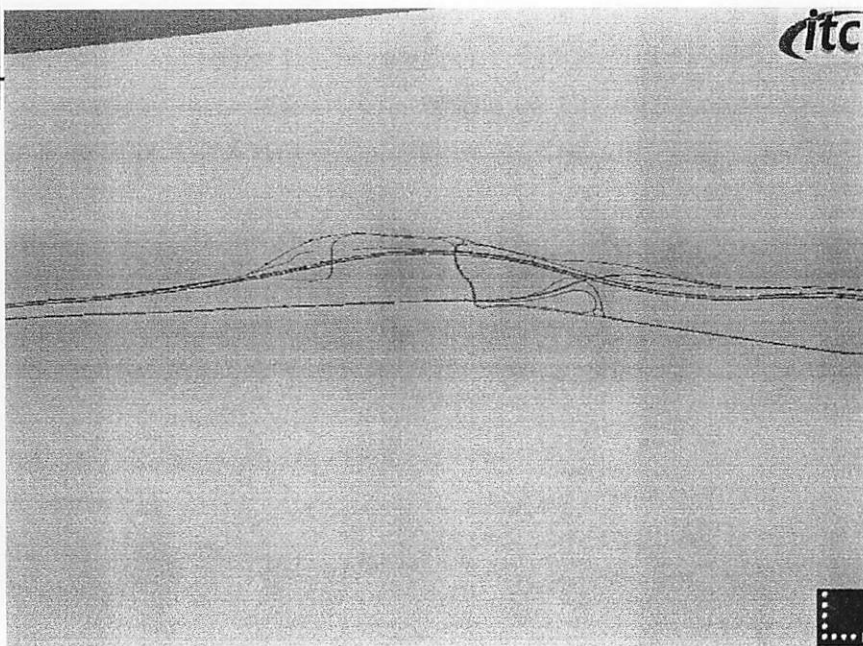


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MIT



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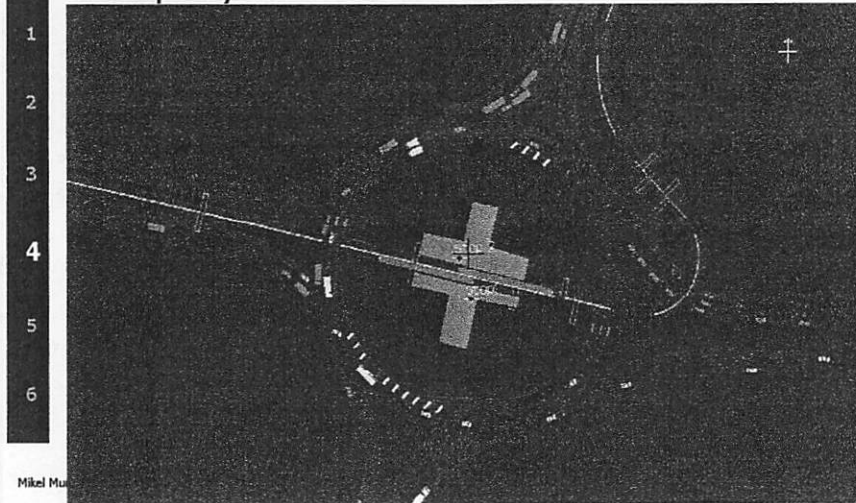


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## Microscopic Traffic Models

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Equally suited for transit...



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## Traffic Models and Real-Time Data

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- Real time traffic data is useful not only for travelers, but to calibrate microscopic models under road incident scenarios
- See for instance [www.bizkaimove.com](http://www.bizkaimove.com) (requiring Flash 6) which provides:
  - Speed maps, running times, live camera...
  - Short Messaging Systems (SMS) sent free to those who have registered

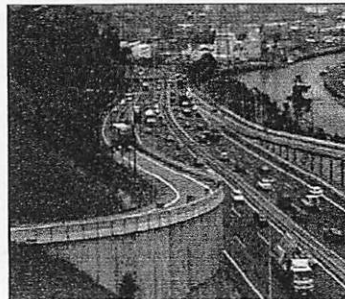
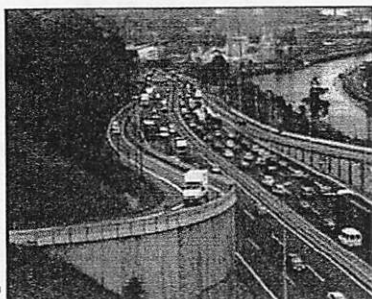
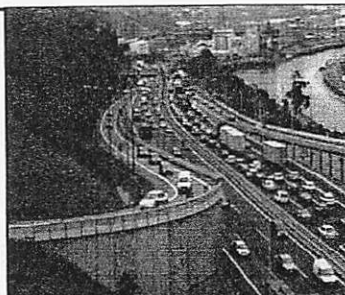
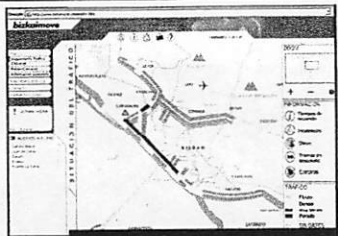


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# MIT Traffic Models and Real-Time Data

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# MIT Visualization: The added advantage

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- 6



Residential density



VS

Job density

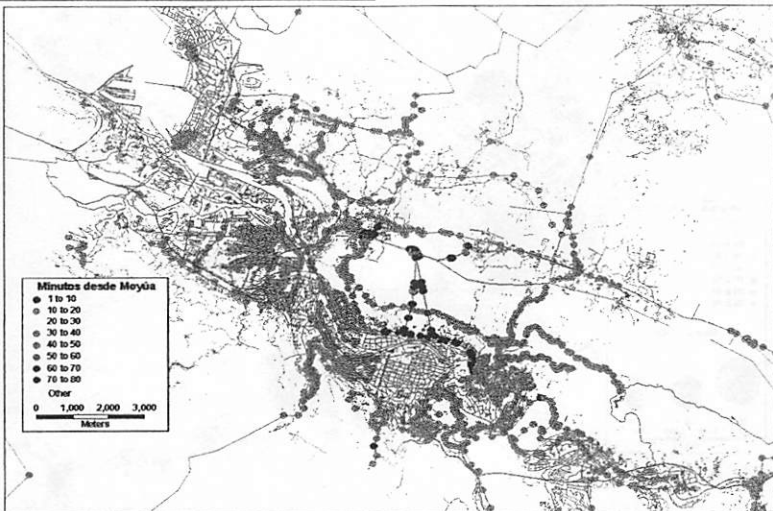
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# MIT Visualization: The added advantage

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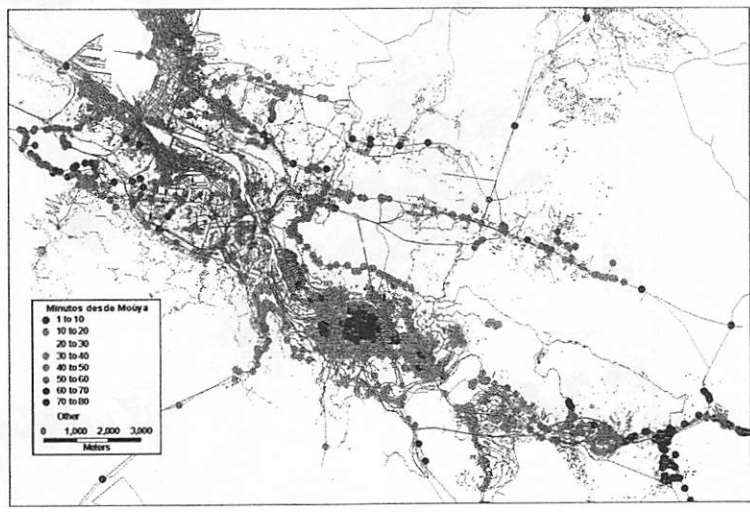
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### Access times by automobile from Moyua

# MIT Visualization: The added advantage

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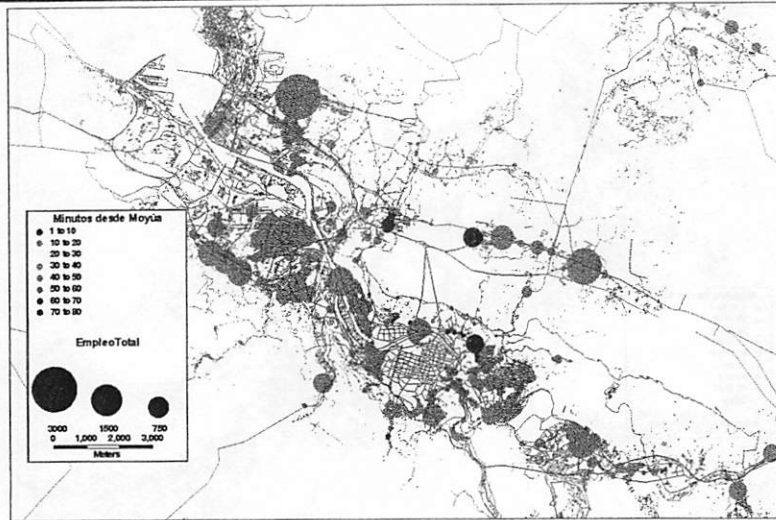
### Access times by transit from Moyua

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# Visualization: The added advantage

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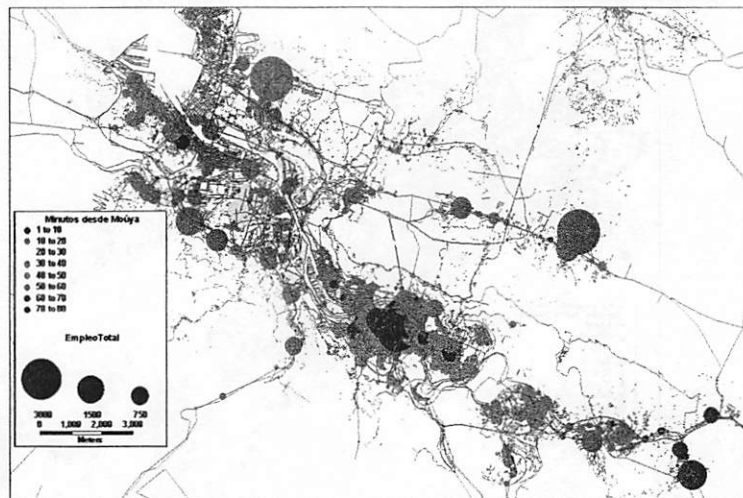
Access times to jobs by automobile from Moyua<sub>67</sub>

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# Visualization: The added advantage

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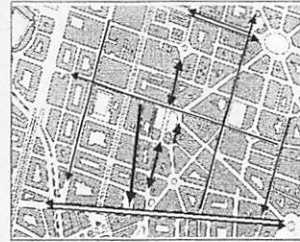
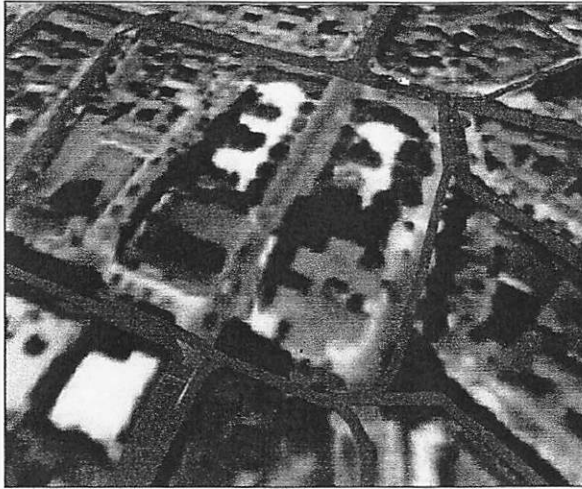
Access times to jobs by transit from Moyua

68

MIT

# Visualization: The added advantage

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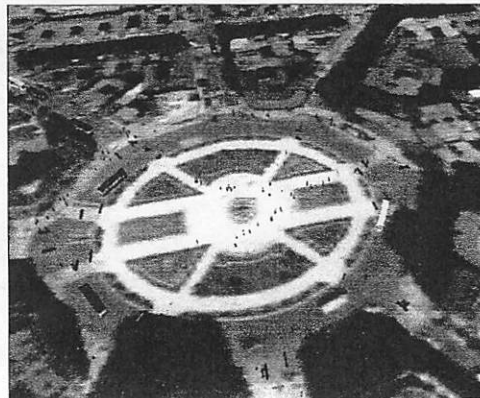
*Saving a plaza*

69

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# Visualization: The added advantage

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- 1
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*Changing the Core*

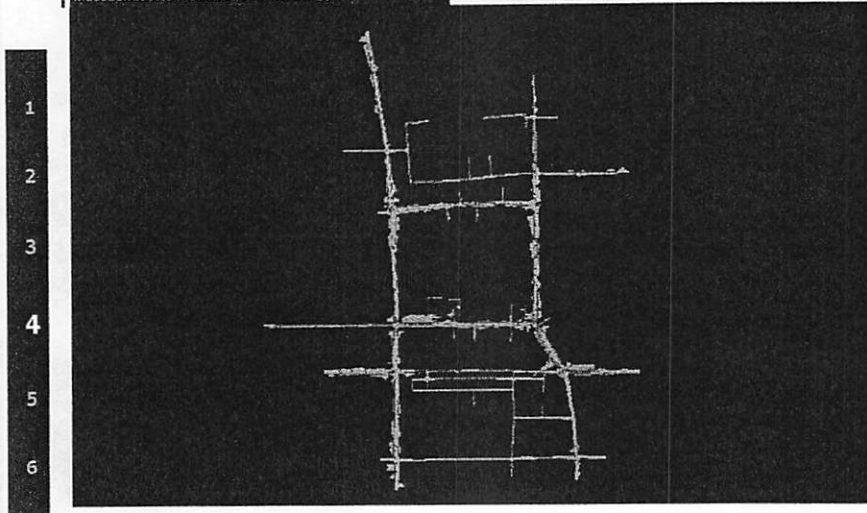
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# Visualization: The added advantage

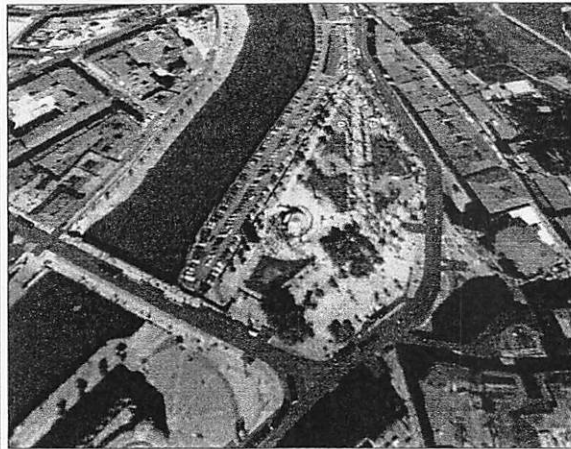
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Environmental impacts

71



## *Transit Only*



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72



## *The new Tram*

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73

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## Integration of the Analytical Chain

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1  
2  
3  
4  
5  
6

- An integrated analytical chain
- Sequence:
  - GIS → Planning Model → Traffic Models → GIS → Postprocessors (environmental studies)
  - Or any combination of the above
- Often just one or two stages needed from the 4-step transport model
- Critical analysis and judgment at every stage

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## MIT In closing...

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### ■ GIS:

- 1
  - 2
  - 3
  - 4
  - 5
  - 6
- It is the basic building block
  - Everyone should be comfortable using GIS
  - Data mining and pattern recognition
  - Essential for data preparation, updating and post-processing of results
  - Most transport and traffic models incorporate GIS capabilities

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## MIT In closing...

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### ■ 4-step transport models:

- 1
  - 2
  - 3
  - 4
  - 5
  - 6
- They entail a great complexity to reconcile human perceptions with travel decisions
  - Their focus has shifted from infrastructure building to system management
  - The impact of it's a real challenge
  - Often only one or two steps are used
  - Calibration, and specially, validation a must

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## MIT In closing...

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### Traffic Models:

- 1 ■ Essential under current oversaturated traffic conditions
- 2 ■ Equally important to analyze incident management strategies
- 3 ■ Most commercial packages are integrated with transport models
- 4 ■ Best used to refine transport model results
- 5 ■ In fact, you should feedback its results
- 6

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## MIT In closing...

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### ■ Visualization:

- 1 ■ It may become critical:
  - 2 ■ To understand analytical results
  - 3 ■ To facilitate public information campaigns
  - 4 ■ To inform decision makers
- 5 ■ Visualization of change through modeling may be the most critical contribution
- 6

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**Finally, do not forget that...**

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**"In Joshua VI, it is recorded that the Israelite army having seven times marched around the city of Jericho, and blown trumpets, and raised a great shout, the walls collapsed.**

**Modern analysts are inclined to march around problems seven times shouting "modal split" or "cost-benefit analysis."**

**The results are not always as satisfying as they were to the Children of Israel"**

**A UTPS Lexicon by Robert H. Watkins and William R. Wolf, 1981**

**Thank you for your attention!**

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## Traffic Assignment

In the case study, a User Equilibrium (UE) traffic assignment technique is applied to compute network link flows. User Equilibrium uses an iterative process to achieve a convergent solution. The process is said to converge when no traveler can improve their travel times by shifting routes (Wardrop equilibrium). The key behavioral assumption with UE is that each traveler has perfect information concerning the attributes of network alternatives, all travelers choose routes that minimize their travel time or travel costs, and all travelers have the same valuations of network attributes.

For each iteration, network link flows are computed, which incorporate link capacity restraint effects and flow-dependent travel times. The flow-dependent travel times are computed based on the Bureau of Public Roads (BPR) formulation. The BPR function relates link travel times as a function of the volume/capacity ratio according to:

$$t = t_f \left[ 1 + \alpha \left( \frac{v}{c} \right)^\beta \right]$$

where:

$t$	=	Congested link travel time
$t_f$	=	Link free-flow travel time
$v$	=	Link volume
$c$	=	Link capacity
$\alpha, \beta$	=	Calibration parameters

In the case study,  $\alpha$  and  $\beta$  are obtained from the network database that contains values for all the links in the network. When the traffic assignment procedure is finished, the final outcome is a table of 24-hour link flows.

## References

There are numerous references able to provide more detailed information on the models used in the 4-step urban transportation planning process, including:

*Travel Demand Modeling with TransCAD*  
(Distributed with TransCAD)  
Caliper Corporation (2002)

*Urban Transportation Planning, Second Edition*  
Michael D. Meyer and Eric J. Miller  
McGraw-Hill Science/Engineering/Math (2000)

*Modelling Transport, Third Edition*  
Juan de Dios Ortuzar and Luis G. Willumsen  
John Wiley & Sons (2001)

Gravity models use friction factors that relate the impedance between zones to the attractiveness between zones. The friction factors may come from an equation, such as exponential or gamma. In the case study, the friction factors are obtained from a lookup table that relates travel times to friction factors.

At the end of trip distribution, a production-attraction matrix exists for each of the four trip purposes.

### Mode Split

Mode split takes the production-attraction trip matrices for the HBW, NHB and HBNW trip purposes that are output from trip distribution, and further splits them into trips made by auto and trips made by bus. The mode split procedure employs a binary logit model to calculate the fraction of trips taken by each mode for each production-attraction pair. The logit model is specified through utility functions for each mode, and this utility represents the attractiveness of the mode (higher is better). The case study uses the following utility specifications:

$$V_{\text{auto}, ij} = -0.05 - 0.08 \cdot \text{AutoTravelTime}_{ij} - 0.105 \cdot \text{ParkingCost}_j + 0.00001 \cdot \text{Income}_i$$

$$V_{\text{bus}, ij} = -0.68 \cdot \text{Fare}_{ij} - 0.08 \cdot \text{InVehicleTravelTime}_{ij}$$

The fraction of trips using a particular mode between any zone  $i$  and any zone  $j$  can then be calculated using the logit equation:

$$\text{Fraction of Trips}_{ij} \text{ Using Bus} = \frac{e^{V_{\text{bus}, ij}}}{e^{V_{\text{bus}, ij}} + e^{V_{\text{auto}, ij}}}$$

$$\text{Fraction of Trips}_{ij} \text{ Using Auto} = \frac{e^{V_{\text{auto}, ij}}}{e^{V_{\text{bus}, ij}} + e^{V_{\text{auto}, ij}}}$$

These fractions are used to divide the total trip matrices (by purpose) output from trip distribution into trips made by auto and trips made by bus. At the end of mode split, two production-attraction trip matrices, one for auto and one for bus, exist for the each of the HBW, NHB and HBNW trip purposes.

### PA to OD

In the case study, the first 3 steps of the 4-step process (trip generation, trip distribution, and mode split) are measured in terms of productions and attractions (PA). The assignment algorithm requires trips to be measured in terms of origins and destinations (OD), so the HBW, NHB and HBNW production-attraction matrices for travel by auto and the production-attraction matrix for the TRUCKTAXI trip purpose must be translated to origin-destination trip matrices. The auto trip matrices for each purpose are summed up in order to determine the total number of vehicle trips originating in a zone  $i$  and destined for zone  $j$ .

Matrices containing external-to-internal trips and external-to-external through trips are also added to produce the final origin-destination auto trip matrix to be used for the traffic assignment procedure.

Once the number of productions and attractions are computed for each zone, a trip balancing method is employed by holding the number of productions constant and adjusting the number of attractions, or vice versa, so that trip ends are conserved in the region.

### Shortest Path Matrix Computation

Using a field containing link travel times in the network, the shortest path between all zones in the network is calculated using a standard shortest path algorithm.

### Trip Distribution

In the case study, a doubly-constrained gravity model is used to determine the distribution of productions and attractions between zones. The gravity model was originally motivated by the observation that flows decrease as a function of the distance separating zones, just as the gravitational pull between two objects decreases as a function of the distance between the objects. As implemented for planning models, the Newtonian analogy has been replaced with the hypothesis that the trips between zones  $i$  and  $j$  are a function of trips originating in zone  $i$  and the relative attractiveness and/or accessibility of zone  $j$  with respect to all zones.

When either productions or attractions are held constant to determine the number of trips produced by zone  $i$  and attracted to zone  $j$ , the gravity model is said to be singly-constrained. In a singly-constrained gravity model, the flow between zones is calculated from one of the following equations, depending on whether the balancing is constrained to productions or attractions:

$$T_{ij} = P_i \cdot \frac{A_j \cdot f(d_{ij})}{\sum_{\text{all zones } z} A_z \cdot f(d_{iz})} \quad \text{(constrained to productions)}$$

$$T_{ij} = A_j \cdot \frac{P_i \cdot f(d_{ij})}{\sum_{\text{all zones } z} P_z \cdot f(d_{zj})} \quad \text{(constrained to attractions)}$$

where:  $T_{ij}$  = the forecast flow produced by zone  $i$  and attracted to zone  $j$

$P_i$  = the forecast number of trips produced by zone  $i$

$A_i$  = the forecast number of trips attracted to zone  $j$

$d_{ij}$  = the impedance between zone  $i$  and zone  $j$

$f(d_{ij})$  = the friction factor between zone  $i$  and zone  $j$

When the doubly-constrained gravity model is applied, an iterative process is used that alternatively balances the rows (productions) and then balances the columns (attractions) using equations slightly more complex than those shown above, until either a convergence criterion is met or a maximum number of iterations is reached. The gravity model applied in the TDFW software is doubly constrained, so the rows of each trip matrix sum up to the productions output from trip generation and the columns sum up to the attractions output from trip generation.

matrices that are output from mode split into origin-destination trip matrices. The outputs are origin-destination trip matrices for each mode.

6. *Traffic Assignment* - Traffic assignment models are used to estimate the flow of traffic on a network, and generates estimates of the link travel times and related attributes that are the basis for benefits estimation and air quality analysis. These models take as input the total auto trip origin-destination matrix output from the PA to OD procedure. The flows for each origin-destination pair are loaded onto the network based on the travel time or impedance of the alternative paths that could carry this traffic. The outputs are the flows and travel times on each link of the network, as well as various summary statistics about travel in the region.

The case study in the TDFW software applies a 24 hour model (that is, it is not broken up into time periods such as peak and off-peak). The study area is divided into 390 TAZs, and the trips purposes are:

- Non-home-based (NHB)
- Home-based work (HBW)
- Home-based non-work (HBNW)
- Truck/taxi (TRUCKTAXI)

### **Trip Generation**

In the case study, productions are computed by cross-classification analysis. A cross-classification analysis groups individual households according to common socio-economic characteristics (e.g. income) so as to create groups with relatively homogeneous trip-making behavior. Inputs to the trip production procedure are the average trip production rates computed for each of the classification groups (i.e., the average number of trips per day by purpose for each household type), which is usually computed from a travel survey. The case study makes use of a table of household production rates by trip purpose, where the household classification is based on *household size* and *income*. These trip rates are then applied to each zone (based on the average household size and average income of the households in the zone) to determine the total number of trips produced by each zone.

Trip attractions, on the other hand, are generated using a regression equation, in which the parameters of the regression equation depend on area type and trip purpose. For each zone, the number of attractions is computed as:

$$N_A = R_1 \cdot HH + R_2 \cdot BASIC + R_3 \cdot RETAIL + R_4 \cdot SERVICE$$

where  $N_A$  = number of attractions,  
HH = number of households,  
BASIC = number of basic employment activity centers (anything not Retail or Service),  
RETAIL = number of retail employment activity centers,  
SERVICE = number of service employment activity centers,  
and  $R_i$  are attraction rates that vary by area type (CBD, CBD fringe, urban, suburban, or rural) and trip purpose.

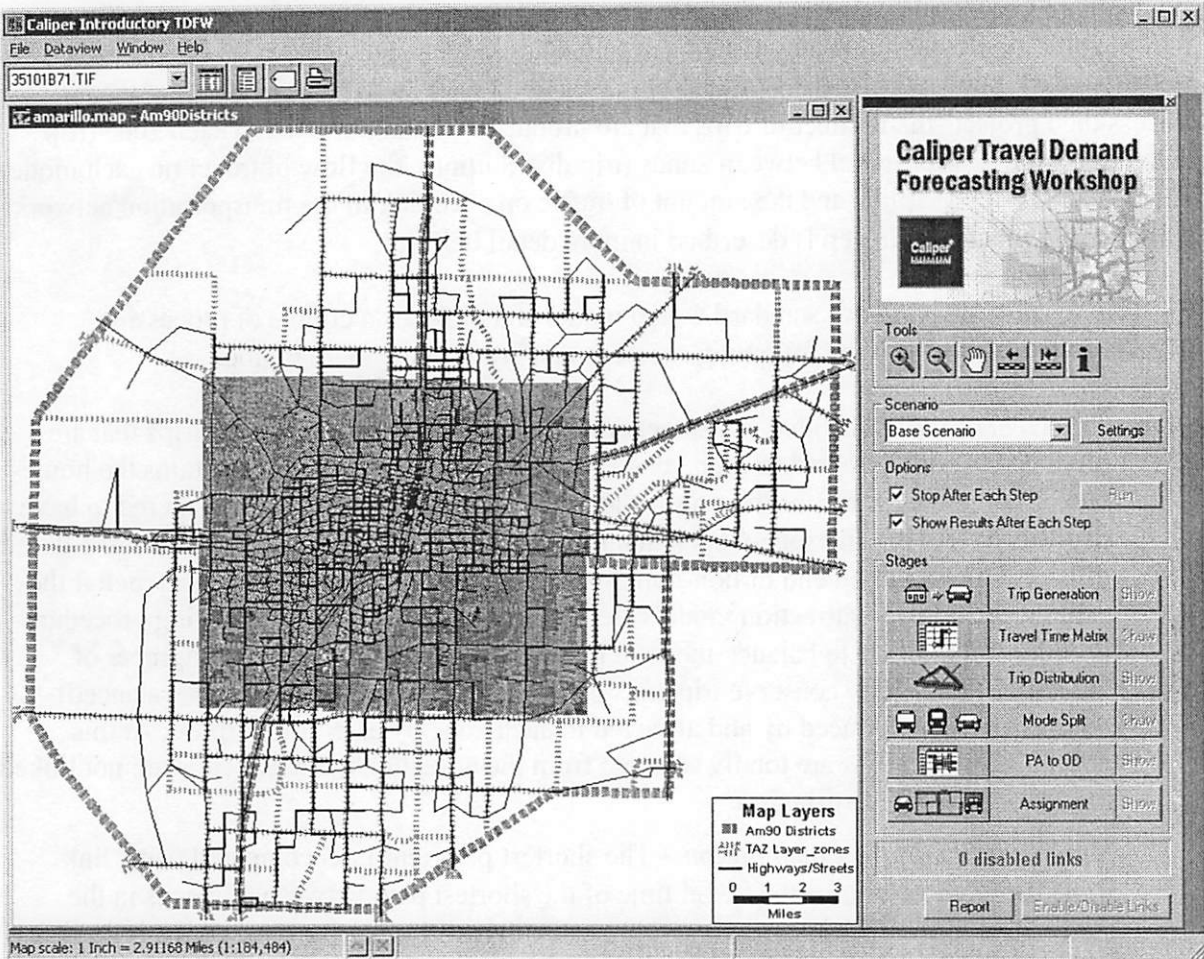
traffic assignment (what roads). Usually, the steps are applied separately for various trip purposes, for example, home-based work, home-based shop, home-based other, and non-home-based. This is because trip-making behavior varies across trip purposes; for example average travel distance varies across purposes as does the relative importance of travel times and travel costs. Furthermore, application of the 4-step process typically requires that a study region is divided into zones, called traffic analysis zones or TAZ for short. These zones are defined such that each has relatively homogenous land use and demographic characteristics, for example, industrial zones, low density residential zones, or high density mixed use zones. The 4-step process then projects the number of trips that are produced by and attracted to each zone (trip generation), the flow of travel between zones (trip distribution), the flow of travel on each mode between zones (mode split), and the amount of traffic on each link in the transportation network (traffic assignment). Each step is described in more detail below.

The TDFW software applies a standard 4-step model and includes a couple of processing procedures, which leads to the following six steps displayed in the main toolbox.

1. *Trip Generation* – The goal of trip generation is to predict the number of trips that are produced by and attracted to each zone in a study area. The zone that contains the home-end of home-based trips or the origin end of non-home-based trips is considered to have **produced** the trip. The zone where an out-of-home activity is undertaken for home-based trips or the destination end of non-home-based trips is considered to have **attracted** the trip. Production and attraction models are applied separately, and a balancing procedure is employed in order to balance the total number of productions and total number of attractions in order to conserve trip ends in the region. The outputs are the (balanced) number of trips produced by and attracted to each zone by each trip purpose. At this point, the productions are totally separate from the attractions; the two ends are not linked into trips until trip distribution.
2. *Shortest Path Matrix Computation* – The shortest path matrix is computed using link impedances to determine the travel time of the shortest path between all zones in the study area. The output is a matrix of shortest path travel times by auto, which is used as input to trip distribution and mode split.
3. *Trip Distribution* - Trip distribution models are used to link the trip productions to the trip attractions and predict the spatial pattern of trips between the zones. The inputs are the trip production and attractions from trip generation and the shortest path travel time matrix, and the outputs are a production-attraction trip matrix for each trip purpose.
4. *Mode Split* - Mode split divides the total trips that are output from trip distribution into trips made by each of the available transportation modes (for example, trips made by auto and trips made by bus). The inputs are the trip matrices from trip distribution, travel time matrices for the available modes (one for bus and one for auto), other service characteristics for the modes (for example, parking costs or bus wait time), and average characteristics of the travelers (for example, average income). The outputs are a trip production-attraction matrix for each trip purpose by each mode.
5. *PA to OD* – The steps above are processed in terms of productions and attractions (defined above). Since the assignment algorithm requires trips to be measured in terms of origins and destinations, it is necessary to translate the productions-attraction trip

# Caliper Introductory Travel Demand Forecasting Workshop Software

## ~ Description of Models ~



The Caliper Travel Demand Forecasting Workshop (TDFW) software is a Windows-based program developed to help students learn the basics about travel demand forecasting and modeling. The software is based on the TransCAD<sup>®</sup> platform. Caliper Corporation developed this program for the FHWA under a contract with the Volpe National Transportation Systems Center. Another document explains how to use the TDFW software. This document provides a brief technical description of the models implemented in the TDFW software. References are provided at the end for further information.

The TDFW software simulates a typical 4-step travel demand model for a relatively small urban area. Travel forecasting models like the 4-step model are used to predict changes in travel and utilization of the transportation system in response to changes in regional development, demographics, and transportation supply. A classic 4-step model consists of the steps of trip generation (how many trips), trip distribution (the flow of trips), mode split (what mode), and