TRAVEL DEMAND MODELING
BASIC CONTEXT

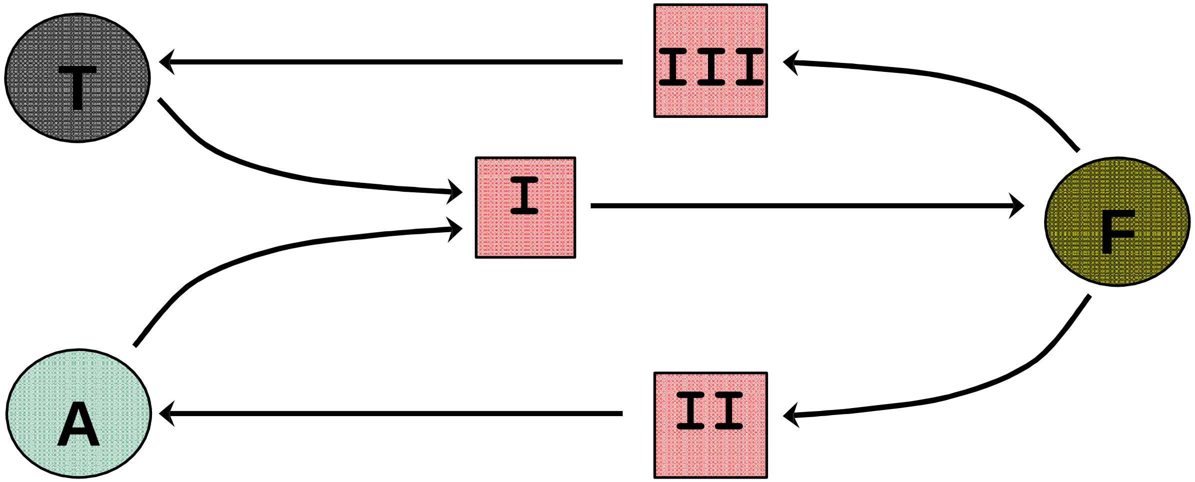
Outline

- Contexts, Objectives and Motivation
- Illustration of model building
- Introduction to travel demand
- Workshop Structure

Conceptual view of Transportation Systems Analysis (TSA)

3 elements in transport system problems:

- Transport system, *T*
- Activity system, *A*
- Flow pattern, *F*



Source: Manheim, M, *Fundamentals of Transportation Systems Analysis*, 1979

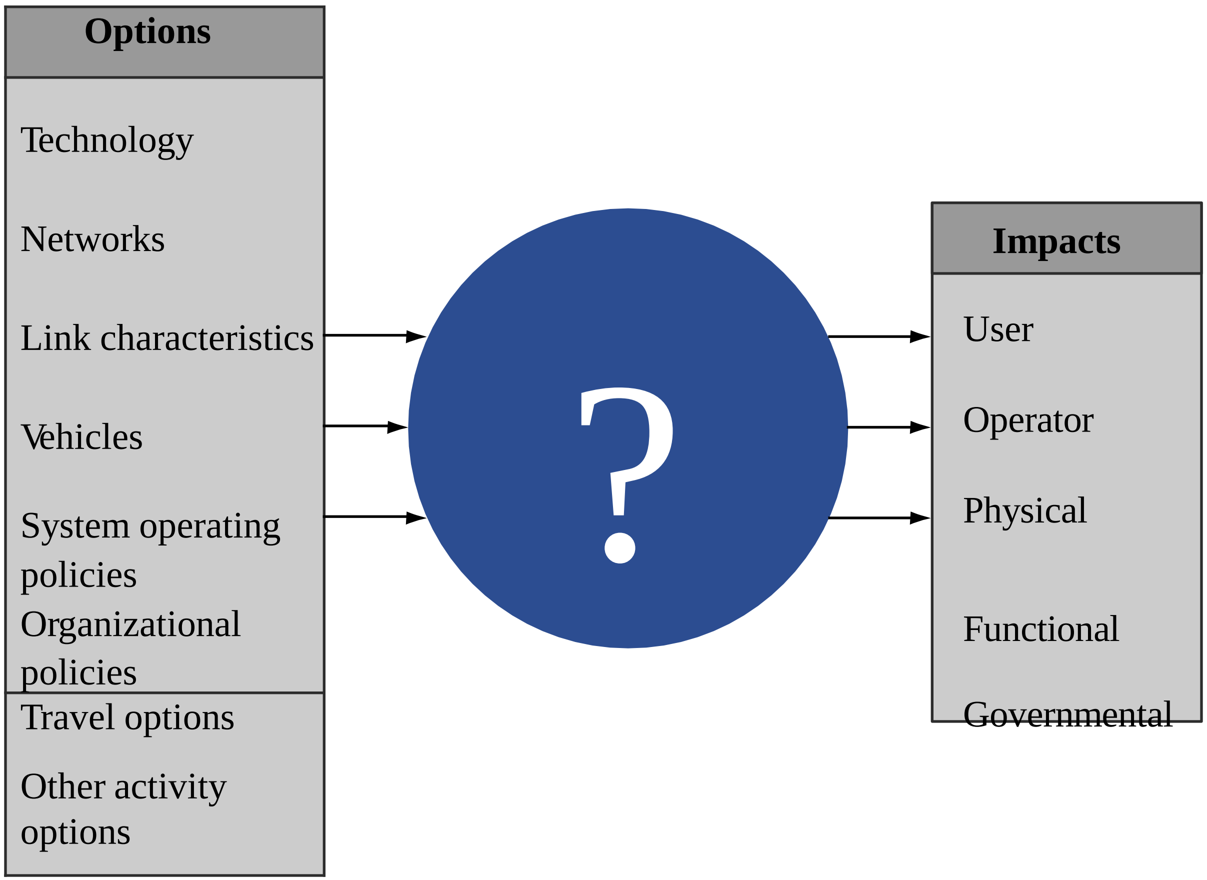
Conceptual view of TSA (2)

- 3 Types of relationships

- Type I (Flow determined by both Transport and Activity systems)
  - Short term outcome (equilibrium)
  - Transportation problems are dynamic (assumed static in instances)
- Type II (Flow pattern causes change over time in the Activity system
  - services provided and resources consumed
- Type III (Flow pattern also causes changes over time in the Transport system)
  - transport operator adds service on a heavily-used route
  - new highway link constructed

Source: Manheim, M, *Fundamentals of Transportation Systems Analysis*, 1979

Models and Prediction



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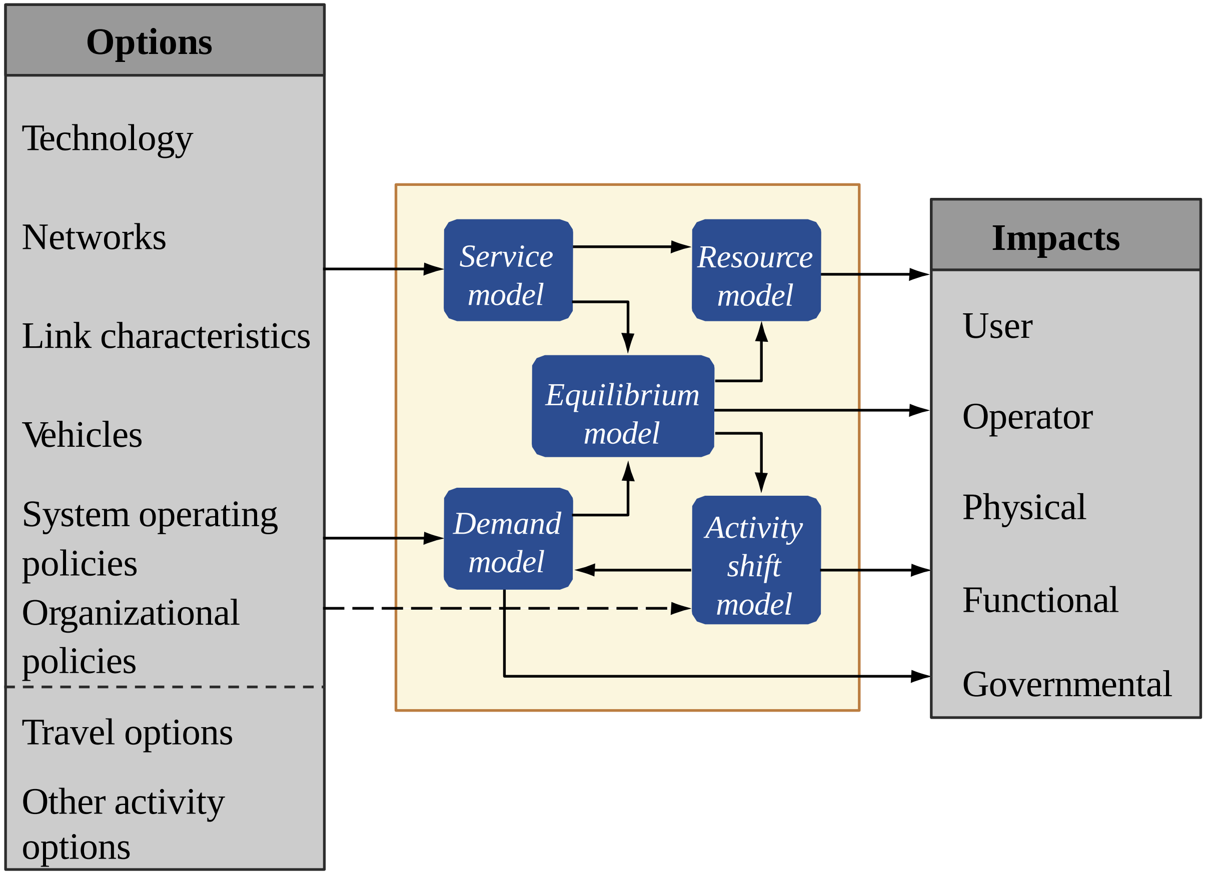
Models and Prediction (2)



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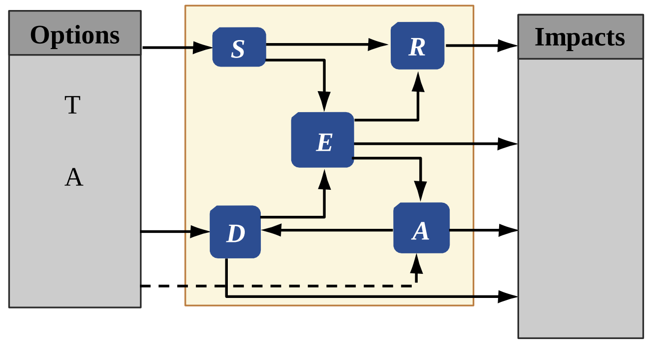
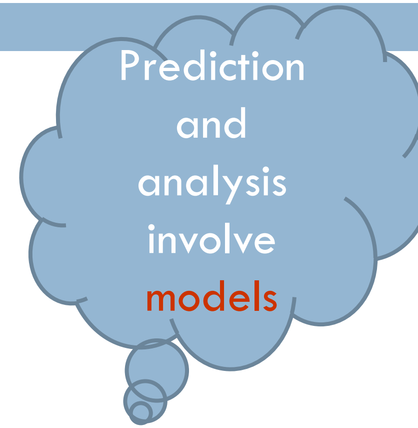
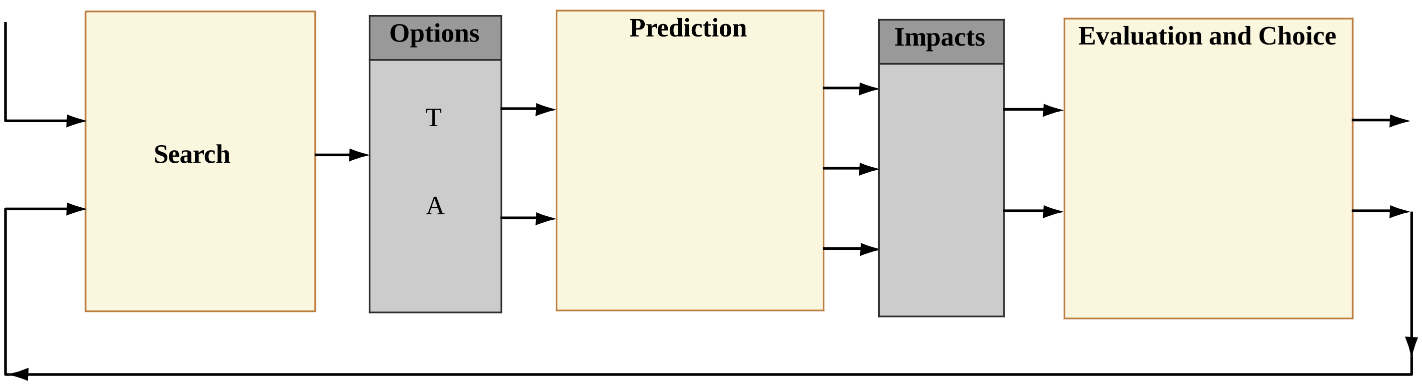
Models and Prediction (3)



A. Prediction





B. Analysis Cycle

Source: Manheim, M, *Fundamentals of Transportation Systems Analysis*, 1979 and MIT OpenCourseWare

Components of a Model

- In general, a model of any situation contains the following five set of elements:
  - Variables over which the planner has *complete control*: *Xi*
  - Variables over which the planner has *no control*: *Zj*
  - Variables over which the planner has *indirect control*: *Yk*
  - General *relationships* between the above variables: *Rm*
  - *Parameters* (coefficients, constants, exponents, etc.) in the above relationship: P_n

Representation of a Model

Symbolically, a model M is represented by

M= { Xi, Zj, Yk, Rm, Pn } for some or all i, j, k, m, n

Where the brackets indicate a set of items.

Example Model

Suppose that the monthly revenue *(r)* for a given bus line

Operation depends on the

Fare charged *(f)*

Monthly number of passengers riding the bus *(p)*

Model Name: Say "Bus Line Operation"

Model Formulation

- Revenue collected
  - Revenue ($)= fare ($/person) * Number of Passengers (persons)
  - $r = f * p$
- It is also found that the number of passengers riding the bus in any month is a function of inches of rainfall
- Now the bus-fare relationship becomes
- $p = \frac{b}{(1+i)(f^{\phi})}$
  - p: number of person riding the system
  - i: inches of rainfall
  - f: fare
  - b, and ϕ are parameters

Model Formulation: Explanation

- Why +1 ?
  - +1 is included so that “no rain” will not result an infinite number of passengers (division by “0”)

- $b\ and\ \phi$ are parameters established from past experience

Hypothetical Case

Original Model: $$p = \frac{b}{(1+i)(f^{\phi})}$$

For example:

In a hypothetical case it may have been found that the ridership = 10,000 passengers (when there is no rain in a month)

Fare = $ 1.00

This would give: $$10{,}000 = \frac{b}{(1+0)(1^{\phi})}$$

$$or$$

$$10{,}000 = b$$

Model Scenario

Let us assume that past data have shown:

Passengers = 40,000 in a month when there was no rain

And corresponding fare = $ 0.50

Put the above values in the original Model

Model Scenario

This would lead to:

$$40{,}000 = \frac{b}{(1+0)(0.5^{\phi})}$$

$$or$$

$$\left(0.5^{\phi}\right) = \frac{10{,}000}{40{,}000}, \qquad (\because b = 10{,}000)$$

$$\left(0.5^{\phi}\right) = 0.25$$

$$\left(0.5^{\phi}\right) = (0.5^{2})$$

$$\phi = 2$$

Model Observations

We notice here,

Complete Control: Fare is a variable over which we (planners) hired by the bus company have control (Xi)

No Control : We do not have any control over the rain (Zj)

Indirect Control : We have indirect control (Yk) over

(1) the number of passengers

(2) revenue

Parameters : b and ϕ

Complete Model Development

We have formulated the model

$$p = \frac{b}{(1+i)(f^{\phi})}$$

But the complete model was

$$r = f \times p = f \times \frac{b}{(1+i)(f^{\phi})}$$

Which leads to

$$r = f\,\frac{10{,}000}{(1+i)(f^{2})}$$

$$r = \frac{10{,}000}{(1+i)(f)}$$

Model Development

Searching further, it can be said that

$$r = \frac{10{,}000}{(1+i)(f)}$$

Model holds true for high income riders.

For lower income riders the proper relationship might be

$$r = \frac{12{,}000}{(1+i)(f)}$$

All Models Till Now

All the models we discussed are symbolic models:

$$r = fp \text{ ....} (1)$$

$$p = \frac{b}{(1+i)(f^{\phi})} \text{ ....} (2)$$

$$r = f\frac{b}{(1+i)(f^{\phi})} \text{ ....} (3)$$

$$r_h = \frac{10{,}000}{(1+i)(f)} \text{ ....} (4)$$

$$r_l = \frac{12{,}000}{(1+i)(f)} \text{ ....} (5)$$

Model Observations

All the models indicate that ,

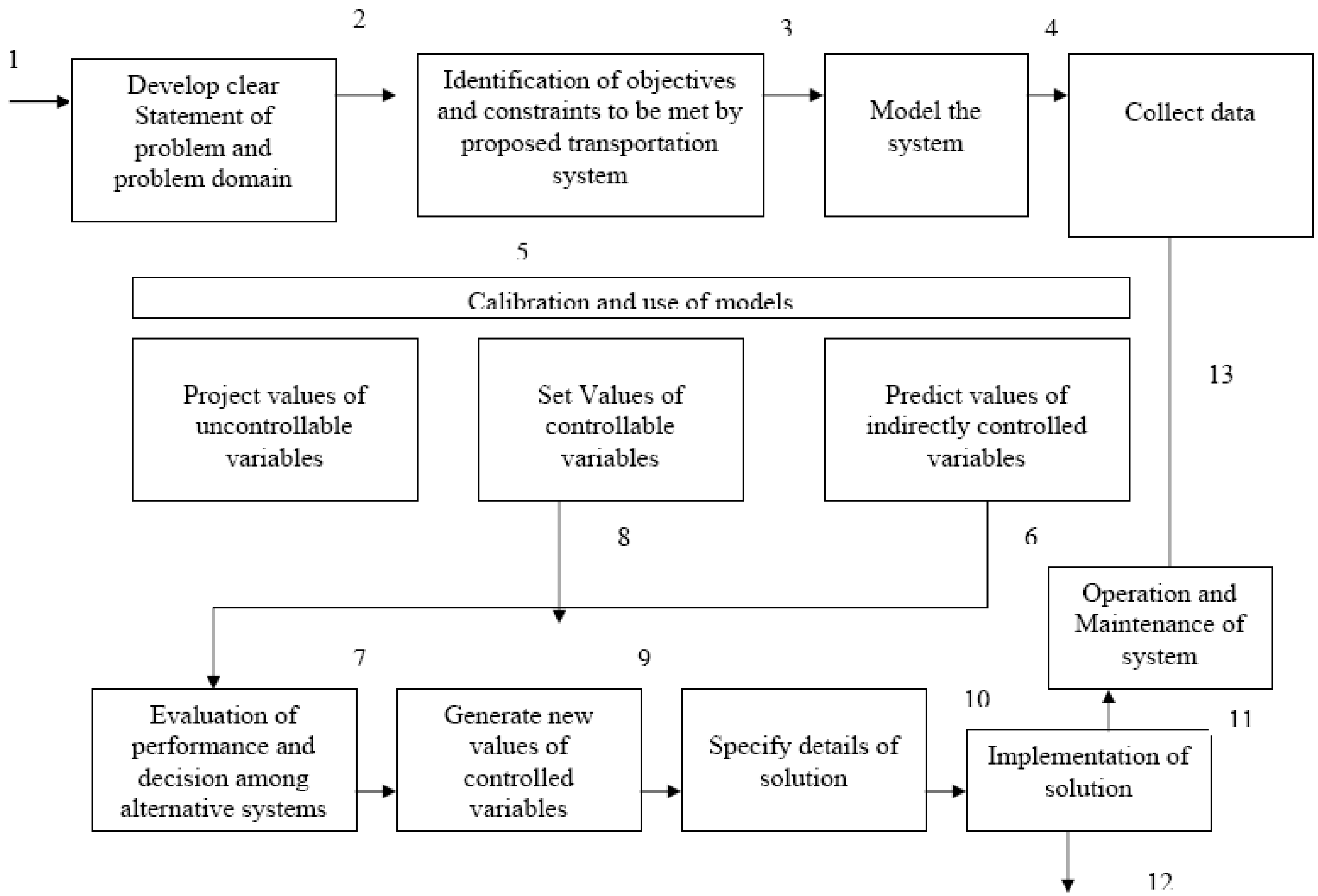
In most general situation indirect variable (like r) is always a function of a controllable variable (like f) and an uncontrollable variable (like i).

Thus,

$$Y_k = f \quad (X_i, Z_j)$$

Which defines "indirect control"

Problem Solving Process



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Model Observations

Suppose the bus company has the problem of having revenue that is too low ***(Stage-1)*** , and realizes that the fare charged, weather and income status of riders all have a bearing on the problem (problem domain)

The company would like to increase its revenue as much as possible

(Objective) ***(Stage-2)***

By modifying the fare structure while at the same time taking into Account many governmental restrictions

(Constraint)

Problem Solving Process Cont..

The models that the agency uses ***(Stage-3)***

$$High\ Income : r = \frac{10{,}000}{(1+i)(f)} \cdots\cdots\cdots\cdots (4)$$

$$Low\ Income : r = \frac{12{,}000}{(1+i)(f)} \cdots\cdots\cdots\cdots (5)$$

At this stage, the local regulating agency requires that the fare should be

$$\$0.10 < f < \$0.40$$

Problem Solving Process Cont..

The net revenue for next month is calculated based on the Projection that amount of rainfall = 1 inch and fare as it is

Today = $ 0.20

(Stage-5)

Under these circumstances, the total revenue will be

$$Total\ Revenue = r_t = \frac{10{,}000}{(1+i)(f)} + \frac{12{,}000}{(1+i)(f)}$$

$$r_t = \frac{10{,}000}{(1+1)(0.20)} + \frac{12{,}000}{(1+1)(0.20)} = \frac{22{,}000}{(2)(0.20)}$$

$$r_t = \$55{,}000\ /\ month$$

Problem Solving Process Cont..

This revenue does not seem to be adequate ***(Stage-6)***

Proposed modification in fare = $ 0.30 ***(Stage-7)***

Modification in fare leads to new generated revenue

$$Total\ Revenue = r_t = \frac{10,000}{(1+i)(f)} + \frac{12,000}{(1+i)(f)}$$

$$r_t = \frac{10,000}{(1+1)(0.30)} + \frac{12,000}{(1+1)(0.30)} = \frac{22,000}{(2)(0.30)}$$

$$r_t = \$36,630 \,/\, month$$

Problem Solving Process Cont..

Again this revenue still is not acceptable ***(Stage-5 and 6)***

Finally after several modifications a fare = \$ 0.10 was suggested

Which leads to the greatest possible net benefit

$$Total\ Revenue = r_t = r_h + r_l = \frac{10{,}000}{(1+i)(f)} + \frac{12{,}000}{(1+i)(f)}$$

$$r_t = \frac{10{,}000}{(1+1)(0.10)} + \frac{12{,}000}{(1+1)(0.10)} = \frac{22{,}000}{(2)(0.10)}$$

$$r_t = \$110{,}000\ /\ month$$

Problem Solving Process Cont..

To implement this fare change, the bus company must notify prospective passengers, get new change machines for the drivers, and in general, specify many of the details ***(Stage-8)*** needed for the satisfactory fulfillment of the innovation

Data Collection Stage

Finally, the fare change is brought into effect ***(Stage-9)***

Operated and maintained ***(Stage-10)***

After a month of experience, with modification, it turns out that the revenue received is not \$110,000 but \$100,000.

To locate possible causes for this discrepancy, the bus company collects some more data (Feedback to Stage-4)

and finds the equation for high income group should be

$$r_h = \frac{8{,}000}{(1+i)\,f}$$

Final Calibration Stage

Entering the new formed equation,

$$Total\ Revenue = r_t = r_h + r_l = \frac{8,000}{(1+i)(f)} + \frac{12,000}{(1+i)(f)}$$

$$r_t = \frac{8,000}{(1+1)(0.10)} + \frac{12,000}{(1+1)(0.10)} = \frac{20,000}{(2)(0.10)}$$

$$r_t = \$100,000\ /\ month$$

Similar procedure would be followed month after month to solve related problems as they arise.

Optimization Technique

Optimization is a robust, mathematically sound technique originally developed in the field of Industrial Engineering and Operation Research

- *An Objective Function*
    - Maximize / Minimize
    - Linear / Non-Linear
- *Constraints / Limitations*
    - Inequalities / Equalities
- *Techniques*
    - Linear Programming
    - Dynamic Programming
    - Integer Programming
- *A set of Decision Variables*

Optimization Technique

A production company (small paint factory) produces both interior and Exterior house paints for wholesale distribution

Two basic raw materials, A and B, are used to manufacture the paints

Maximum availability of A : 6 tons a day

Maximum availability of B : 8 tons a day

The daily requirement of the raw materials per ton is as following

Material	Raw Material Per Ton of Paint		Max. Available
	Exterior	Interior	
Raw Material A	1	2	6
Raw Material B	2	1	8

Objective Function

Variables:

Xe = tons produced daily of exterior paint
Xi = tons produced daily of interior paint

Before Information: 1 ton of Xe = $3,000 and 1 ton of Xi = $2,000

Objective: Maximize the revenue by selling both interior and exterior paint

Objective Function:

Maximize

$$Z = 3X_e + 2X_i$$

Limitations

1. $$\begin{pmatrix} \textit{Usage of raw material} \\ \textit{by both paints} \end{pmatrix} \leq \begin{pmatrix} \textit{Maximum of raw material} \\ \textit{availability} \end{pmatrix}$$

2. $$\begin{pmatrix} \textit{Excess amount if interior} \\ \textit{over exterior paint} \end{pmatrix} \leq \textit{1 ton per day}$$

3. $$(\textit{Demand for interior paint}) \leq \textit{2 tons per day}$$

4. *Amount produced of each paint cannot be negative*

Constraints

Subjected to:

$$Xe + 2Xi \leq 6 \text{ ....}(1)$$

$$2Xe + Xi \leq 8\text{.... ....}(2)$$

$$-Xe + Xi \leq 1\text{.................}(3)$$

$$Xi \leq 2\text{..............................}(4)$$

$$Xe \geq 0\text{..............................}(5)$$

$$Xi \geq 0\text{..............................}(6)$$

Complete Problem

Maximize

$$Z = 3Xe + 2Xi$$

Subjected to:

$$Xe + 2Xi \leq 6 \text{ ....}(1)$$

$$2Xe + Xi \leq 8\text{.... ....}(2)$$

$$-Xe + Xi \leq 1\text{................}(3)$$

$$Xi \leq 2\text{..........................}(4)$$

$$Xe \geq 0\text{.........................}(5)$$

$$Xi \geq 0\text{..........................}(6)$$

Computer Technique:

Solver Technique

Steps:

1. Choose cells for the variables, objective function, and constraints
2. Give initial values for the variables
3. Formulate the objective function
4. Formulate all the constraints
5. Go to Tools, Solver in Microsoft Excel
6. Choose the Varying Cells (Variable Cells)
7. Set whether to maximize or minimize
8. Add all the constraints
9. Check all your inputs
10. Now Press Solve

How does the transportation system look?

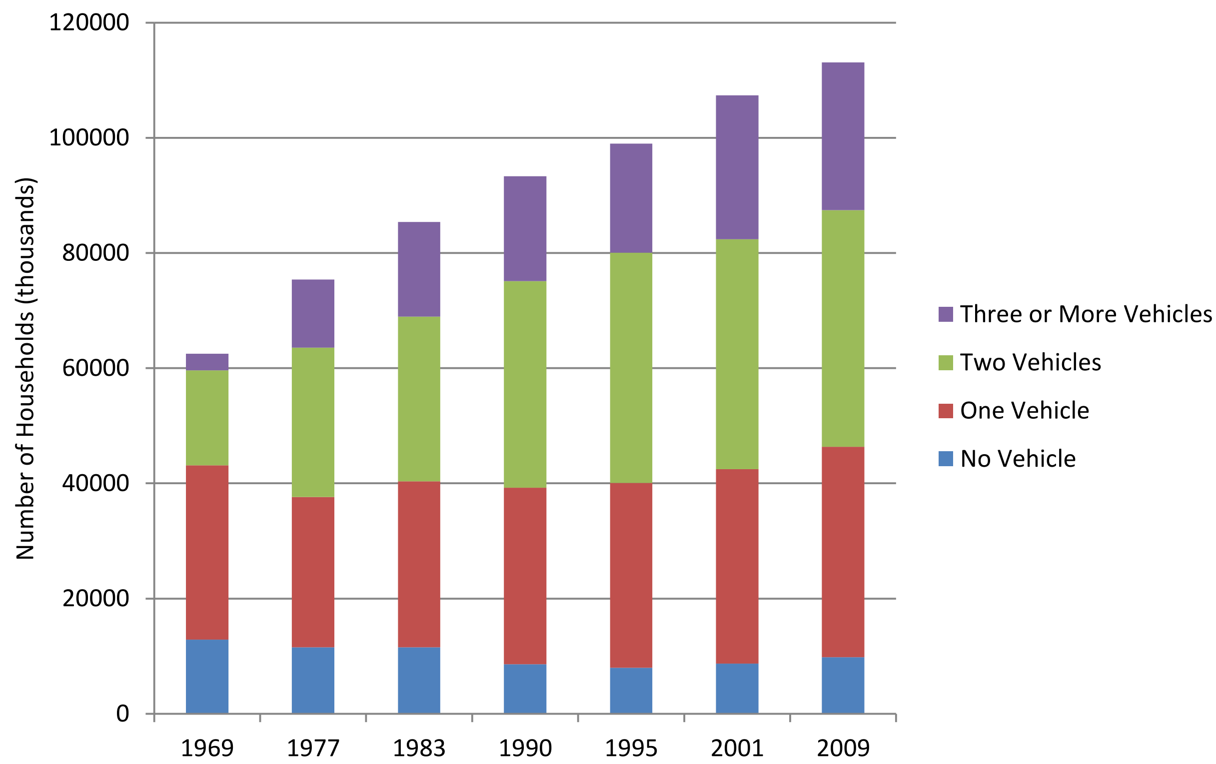
- Observations over time
- Household and individual travel patterns
- Origins and destinations
- Primary mode of travel
- Primary time of day travel
- Primary route of travel

Travel Characteristics

Major Travel Indicators by Survey Year							
	1969	**1977**	**1983**	**1990**	**1995**	**2001**	**2009**
Persons per household	3.16	2.83	2.69	2.56	2.63	2.40	2.50
Vehicles per household	1.16	1.59	1.68	1.77	1.78	1.87	1.86
Licensed drivers per household	1.65	1.69	1.72	1.75	1.78	1.77	1.88
Vehicles per licensed driver	0.7	0.94	0.98	1.01	1	1.06	0.99
Workers per household	1.21	1.23	1.21	1.27	1.33	1.35	1.34
Vehicles per worker	0.96	1.29	1.39	1.4	1.34	1.39	1.39

- While *household size has declined* in the U.S., all other major travel indicators increased between 1969 and 2009.
- Over the last four decades household acquired *more vehicles, more drivers*, and *more workers*.

Households vs. Vehicle Ownership



Approximately 40 million households have owned either zero or one vehicle since 1969. In 1969 those forty million households represented nearly 70 percent of households, while in 2009 the same number is less than 40 percent of all households.

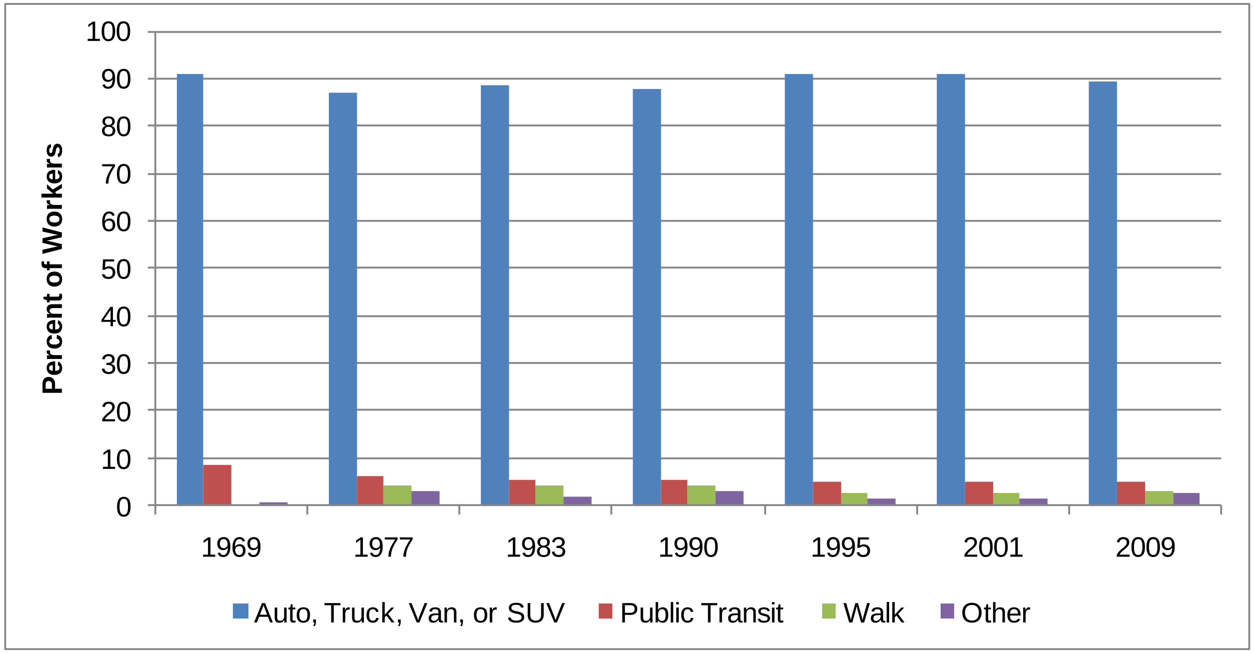
On the other hand, just 2.8 million households in 1969 owned three or more vehicles, less than 5 percent of all households. That number has grown by nearly tenfold--to 25 million households, which in 2009 represented 23 percent of all households.

Vehicle Miles of Travel

	1969	1977	1983	1990	1995	2001	2009
Commute Vehicle Trips (000,000)	27,844	31,886	35,271	41,792	54,782	51,395	51,699
Commute VMT (000,000)	260,716	287,710	301,644	453,042	642,610	614,548	623,479
Total VMT (000,000)	775,940	907,603	1,002,139	1,695,290	2,068,368	2,274,797	2,245,112
% Commute VMT of Total VMT	33.60%	31.70%	30.10%	26.72%	31.07%	27.02%	27.77%
Workers (000)	75,758	93,019	103,244	118,343	131,697	145,272	151,373
Annual Commute Vehicle Trips per Worker	368	343	342	353	416	354	342

- The number of commute vehicle trips, the vehicle miles of travel (VMT) for commuting, and the total vehicle miles for commuting are about the same as the 2001 estimate (within the margin of error).
- The total estimated number of workers increased between 2001 and 2009, while the annual commute vehicle trips per worker decreased.

Mode of Travel

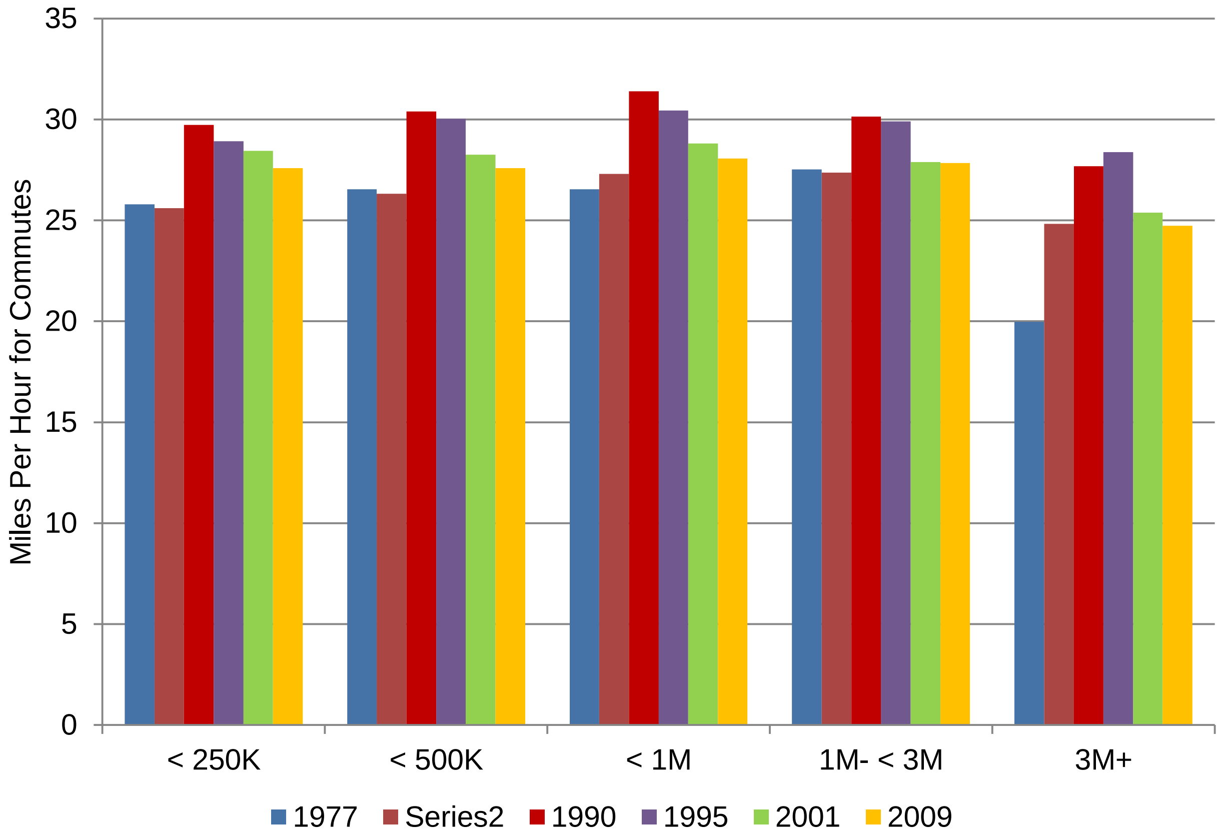


- The usual mode is defined as the means of transportation usually used to go to work in the week prior to the travel day.
- Public Transit includes local bus, commuter bus, commuter train, subway, trolley, and streetcar.
- Other includes other modes not shown above such as motorcycle, Amtrak, airplane, taxi, bike, school bus, and other.

Commute Pattern

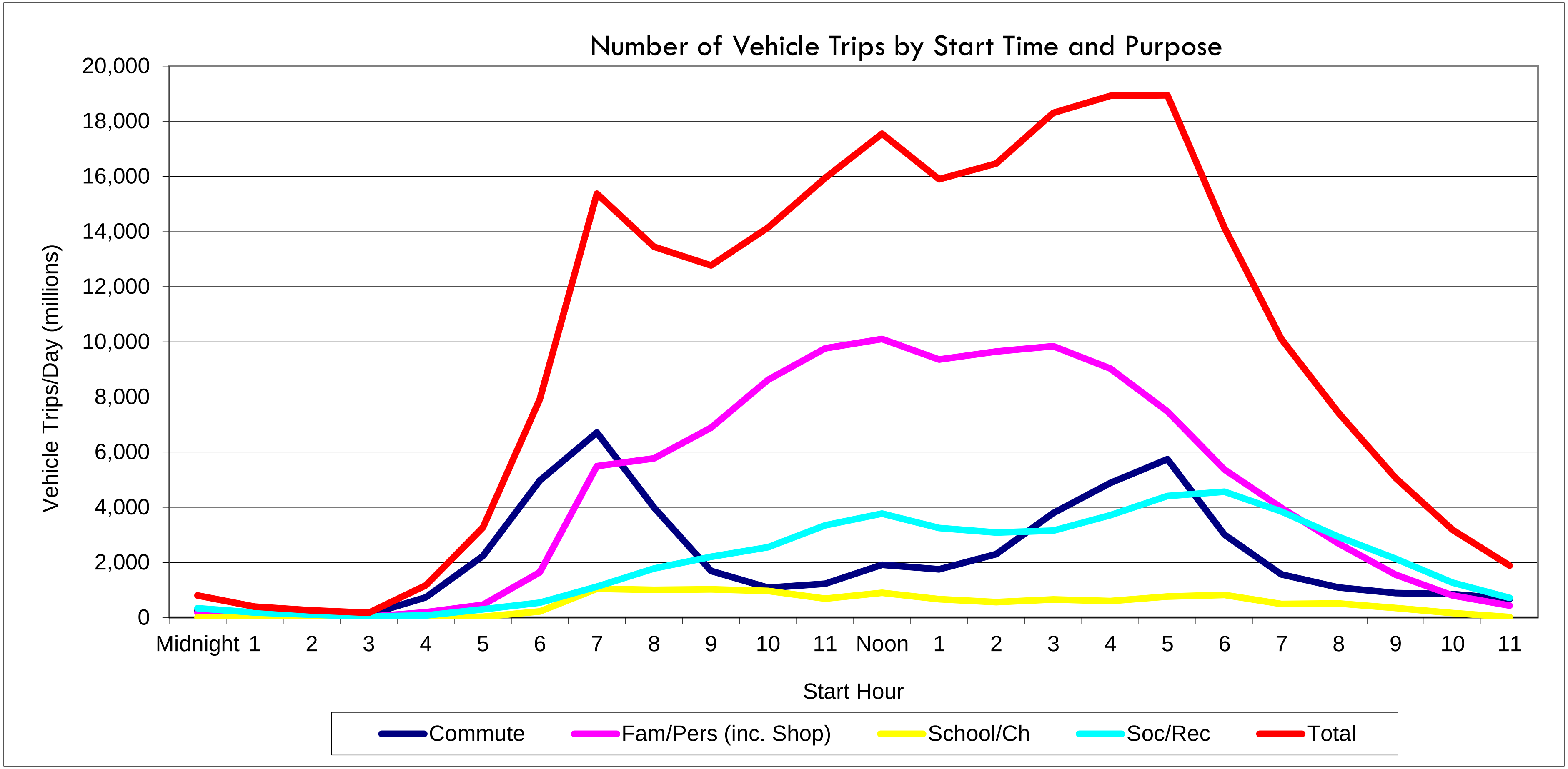
	1977	1983	1990	1995	2001	2009	95% CI
All	All Modes						
Average Commute Trip Length (miles)	9.06	8.54	10.65	11.63	12.11	11.79	0.29
Average Commute Travel Time (minutes)	19.23	18.20	19.60	20.65	23.32	23.85	0.35
Average Commute Speed (miles per hour)	34.72	26.84	33.35	34.67	32.23	27.50	0.33
Private Vehicle	Private Vehicle						
Average Commute Trip Length (miles)	9.61	8.86	11.02	11.84	12.10	12.09	0.25
Average Commute Travel Time (minutes)	18.95	17.62	19.05	20.10	22.49	22.85	0.34
Average Commute Speed (miles per hour)	37.50	27.78	31.49	35.18	32.27	28.87	0.31
Public Transit	Public Transit						
Average Commute Trip Length (miles)	7.48	9.00	12.75	12.88	11.73	10.18	1.54
Average Commute Travel Time (minutes)	37.59	37.79	41.10	41.95	55.50	52.98	4.19
Average Commute Speed (miles per hour)	12.58	15.44	18.02	18.22	12.96	11.42	0.99
Walk	Walk						
Average Commute Trip Length (miles)	-	-	0.83	0.74	0.91	0.98	0.23
Average Commute Travel Time (minutes)	-	-	9.79	10.86	14.06	16.15	2.28
Average Commute Speed (miles per hour)	-	-	4.99	3.58	3.18	4.77	0.51

Commute Speeds by MSA



- The average speed of commuting by all modes has declined slightly in all metro areas, regardless of size.
- Since 1990, the middle-sized metro areas have seen the greatest decline in commute speed.
- For instance, in 1990 areas between 500 thousand and one million in population had calculated average commute speeds of 31.4 miles per hour versus 28 miles per hour in 2009

Trip Purpose and Start Time



As expected, commuting to and from work began predominately between 6 and 9 o'clock in the morning and between 4 and 7 o'clock in the afternoon while more than half of non work-related trips started between 9 am and 4 pm.

Weekday and Weekend Travel

Daily Travel Statistics	1990		1995		2001		2009	
	Weekday	Sat/Sun	Weekday	Sat/Sun	Weekday	Sat/Sun	Weekday	Sat/Sun
Vehicle Trips per Driver	3.41	2.89	3.81	2.99	3.56	2.85	3.21	2.53
% work trips	*27.80%*	*9.70%*	*31.90%*	*12.50%*	*31.20%*	*10.60%*	*30.99%*	*10.14%*
% non-work trips	*72.20%*	*90.30%*	*68.10%*	*87.50%*	*68.80%*	*89.40%*	*69.01%*	*89.86%*
VMT per Driver	28.54	28.36	33.46	28.87	34.35	28.70	30.55	25.01
Average Vehicle Trip Length	8.47	9.96	8.85	9.73	9.75	10.22	9.62	10.03
Average Time Spent Driving (in minutes)	50.68	46.07	59.48	48.05	64.79	52.39	59.83	46.68
Person Trips per Person	3.82	3.60	4.43	3.96	4.18	3.86	3.91	3.51
PMT per Person	32.6	40.64	37.68	41.14	39.41	42.31	35.76	37.05
Average Person Trip Length	9.47	11.51	8.63	10.53	9.60	11.18	9.37	10.80

Gasoline Consumption

Household Location	2001 Dollars/Year	2009 Dollars/Year
All	$ 1,274.55	$ 3,308.38
One Vehicle	$ 556.13	$ 1,431.74
Two Vehicle	$ 1,324.72	$ 3,414.65
Three or more Vehicles	$ 2,166.10	$ 5,805.61
All Urban	$ 1,178.07	$ 2,981.09
Urban One Vehicle	$ 538.12	$ 1,382.15
Urban Two Vehicle	$ 1,285.99	$ 3,290.29
Urban Three or more Vehicles	$ 2,065.38	$ 5,402.64
All Rural	$ 1,622.62	$ 4,338.65
Rural One Vehicle	$ 660.79	$ 1,701.37
Rural Two Vehicle	$ 1,469.22	$ 3,804.67
Rural Three or more Vehicles	$ 2,379.02	$ 6,515.68

- When weighted to an annual estimate, an average household in the 2009 NHTS sample spent about $3,300 per year for gasoline for all the vehicles in the household. The same estimate for an average household in the 2001 NHTS was $1,275. These data show that the average expenditures on gasoline by U.S. households have more than doubled since 2001.
- Urban households spend less overall than rural households because they travel fewer miles for everyday trips and generally own smaller vehicles that are more fuel efficient.

Why Bother?

- Need to know
  - Where am I now?
  - How should my system look in the future?
  - How will I make this reality?
- Future transportation system vision
  - Assessment
  - Decisions
  - Information exchange

Basic Assumptions

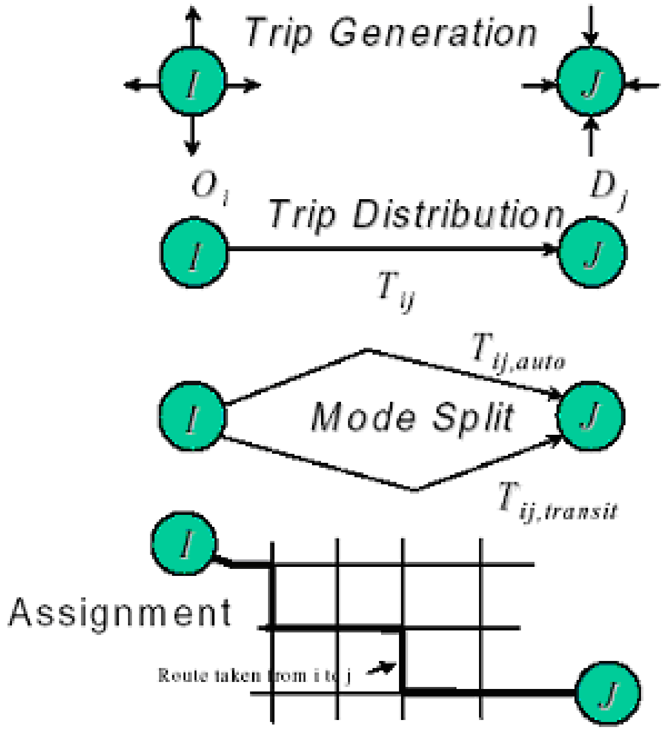
- Tripmaking is a function of land use
- Trips are made for specific purposes
- Different trip types are made at different times of the day
- Travelers have options available to them
- Trips are made to minimize inconvenience
- System modeling is based on Traffic Analysis Zones and networks

Traveler Decisions

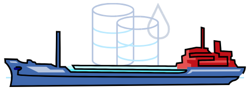
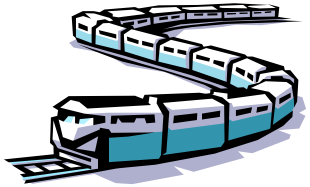
- Temporal
  - When to travel
  - What time to travel
- Destination
- Modal (car, bus, walking, etc.)
- Spatial or route
- Long- & Short-term factors

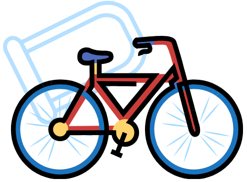
4 Step Process and more

- Trip generation
- Trip distribution
- Modal split
- Trip Assignment
- A fifth step
  - Time-of-day
- Feedback and equilibrium?



Where Applied

More than roadways

Transportation Planning in the U.S.

- Decentralized – primary responsibilities with the States and localities/regions
- Major Policy and Planning Issues
  - Air Quality
  - Land Use and Transportation
  - Public Involvement
  - Freight
  - Transit
  - Pricing
  - Others

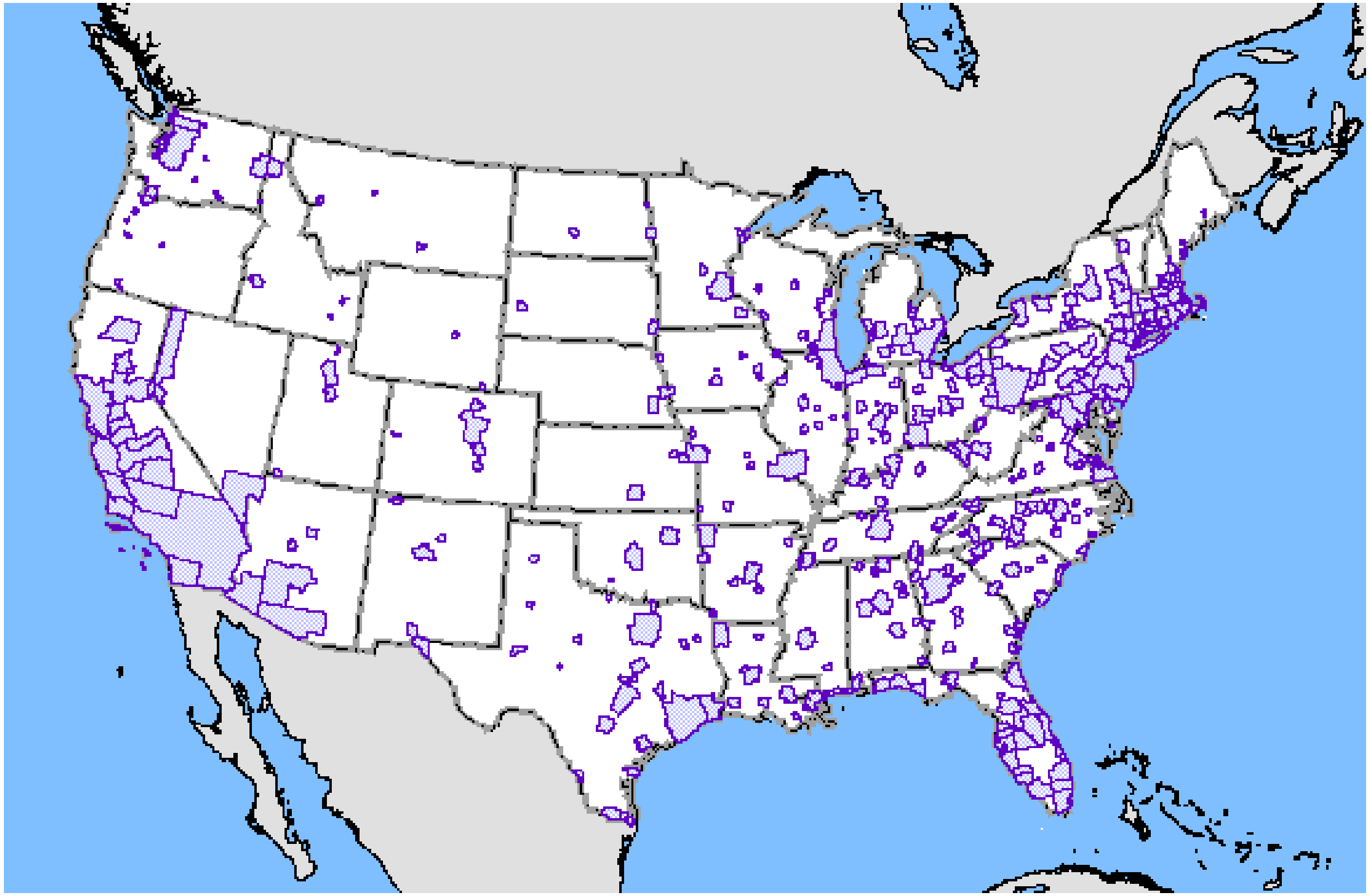
Transportation Planning in the U.S. (2)

- U.S. Department of Transportation (US DOT)- Level I
  - Implements law, sets policies, and provides guidance on planning issues
  - Reviews, approves, and certifies selected planning activities/documents
- State Department of Transportation (State DOT) – Level II
  - Develops statewide transportation plans and programs
  - Coordinates with MPOs and neighboring States
  - Plans for non-urbanized areas
- Metropolitan Planning Organization (MPO) – Level III
  - Develops metropolitan transportation plans and programs
  - Coordinates with neighboring MPO(s) and State(s)
  - Public Participation and Stakeholder Involvement

What is MPO

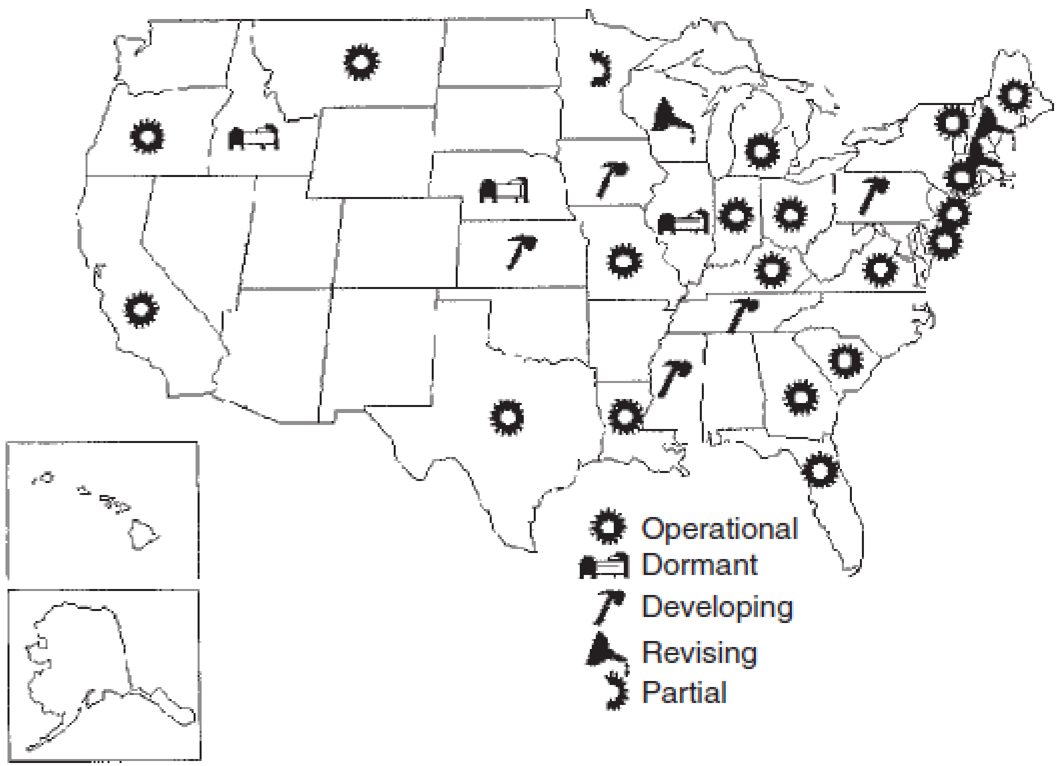
- Metropolitan Planning Organization (MPO)
  - Forum for cooperative transportation decision-making for an urbanized area (population of 50,000 +)
  - Established according to 23 USC 134(d)
  - Conducts the **"3-C"** planning process – Continuing, Cooperative, and Comprehensive
  - Members: local governments, public transportation agencies, and others (e.g., airport and seaport agencies)
    - State DOT can be a voting or nonvoting member of the MPO Board
    - The public must play a large role in the process

MPOs in the US



384 MPOs

Do All MPOs and State DOTs Have Travel Demand Models?



About 22 states have operational models

Applications

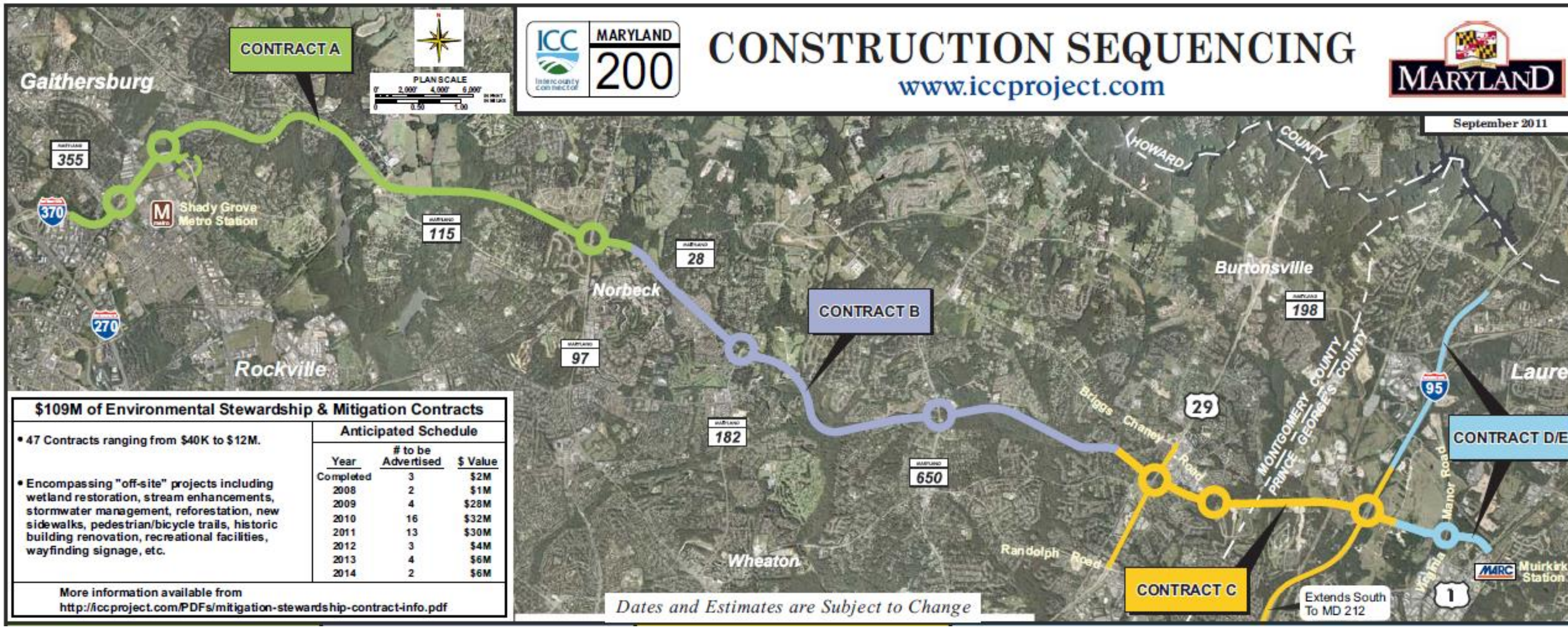
- Congestion Pricing
- New Infrastructure
- Air Quality / Emission
- Financing
- Work Zone / Rerouting
- Passenger / Freight Modeling

Congestion Pricing

- The financial cost of congestion:
  - 3.7B hours of delay and
  - 2.3B gallons of wasted fuel annually*
  - Almost $200B after accounting
    - for unreliability, inventory, and
    - environmental costs across
    - all modes**

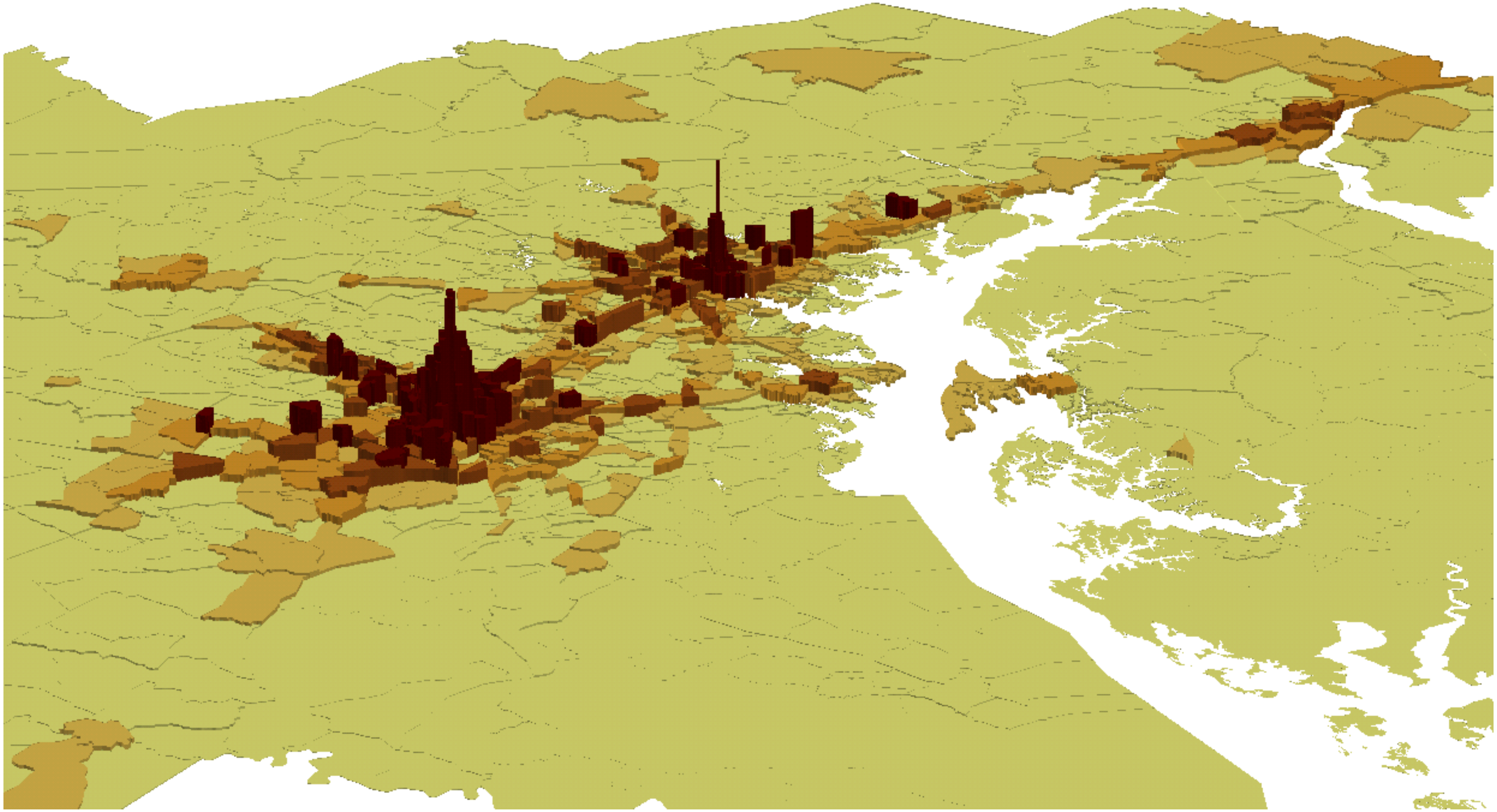
TDM Application ?

New Infrastructure



TDM Application ?

Air Quality / GHG



TDM Application ?

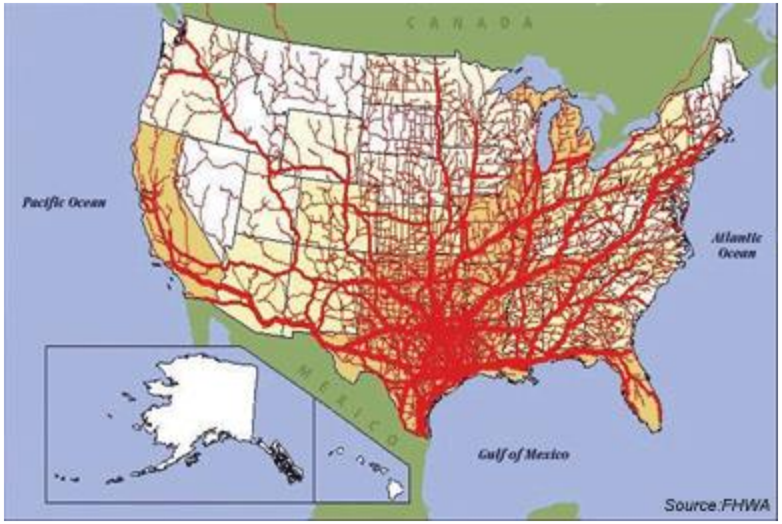
Financing / Traffic Growth

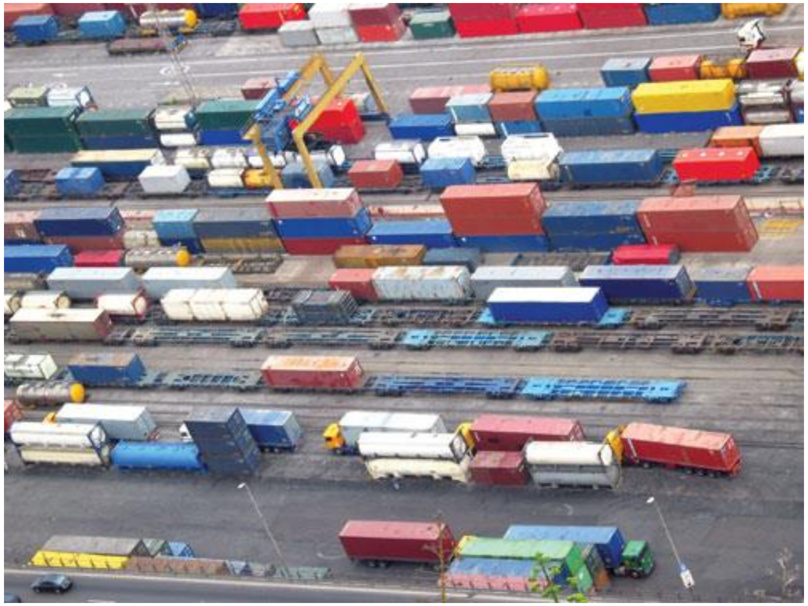
TDM Application ?

Work Zone / Rerouting

TDM Application ?

Freight Modeling





TDM Application ?

Short Term Course Structure

Date (m/d/y)	Session-1 (9:30am-10:30am)	Session-2 (10:45am - 11:45am)	Session-3 (1:30pm-2:30pm)
12/11/2016	1. Travel Demand Modeling (Basics)	2. Trip Gen	Lab-1
12/12/2016	3. Trip Distribution	4. Mode Choice	Lab-2
12/13/2016	5. Assignment	6. Integrated TDM	Lab-3
12/14/2016	7. Freight Overview	8. Freight Generation	Lab-4
12/15/2016	9. Freight Trip Generation	10. Freight Trip Distribution	Lab-5
12/16/2016	11. Freight Mode Choice	12. Freight Assignment	Lab-6
12/17/2016	13. National Supply Chain	14. Tour Based Models	Lab-7
12/18/2016	15. Last Mile Delivery	16. Best Practices and Path Ahead	Lab-8
12/19/2016	17. Concluding Session		

Sources and Acknowledgements

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- Dickey, J. W. Metropolitan Transportation Planning, 1983
- MIT Open Courseware, 201j, transportation systems analysis
- Bureau of transportation statistics
- Ortuzar, and Willumsen, Modeling Transport, 2011
- Boyce and Willams, Forecasting Urban Travel, 2016