

ANNOUNCEMENTS

- Homework 3 Due Today
 - Draft Term Paper Due Today
 - Minute Papers Returned
 - Survey Handed Out
 - Next Week Class: Strongly Encouraged to Attend NCTE Dinner (Handout) (Will return marked up Term Papers)
 - Homework 4 Handed Out at End of Class, Due April 27.
 - Two Weeks: Present Term Papers (In alphabetical order):
 - [Joe Bequaud - Dustin Lang] on April 27, (including Pavithra Kaudadai-Parthasarathi)
 - [Fung Kit Lim - Ewa Zofka] on May 4.
- Email Presentations to Wenling Chen wchen@hhh.umn.edu in .ppt and .pdf formats with filenames CE5214-LastName.ppt and CE5214-LastName.pdf by 6 pm April 22. Wenling will install them on laptop before class.

CE5214: LECTURE 9 NETWORK GROWTH

David Levinson

SURFACE TRANSPORTATION NETWORK LAYERS

- 11 Places
 - 10 Trip Ends
 - 9 End to End Trip
 - 8 Driver/Passenger
 - 7 Service (Vehicle & Schedule)
 - 6 Signs and Signals
 - 5 Markings
 - 4 Pavement Surface
 - 3 Structure (Earth & Pavement and Bridges)
 - 2 Alignment (Vertical and Horizontal)
 - 1 Right-Of-Way
 - 0 Space
- Each layer has rules of behavior:
 - some rules are physical and never violated, others are physical but probabilistic.,
 - some are legal rules or social norms which are occasionally violated

COMMUNICATIONS: OSI REFERENCE MODEL

- *7 Application Layer* - The Application Layer is the level of the protocol hierarchy where user-accessed network processes reside.
 - *6 Presentation Layer* - For cooperating applications to exchange data, they must agree about how data is represented. In OSI, this layer provides standard data presentation routines.
 - *5 Session Layer* - As with the Presentation Layer, the Session Layer is not identifiable as a separate layer in the TCP/IP protocol hierarchy. The OSI Session Layer manages the sessions (connection) between cooperating applications.
 - *4 Transport Layer* - Much of our discussion of TCP/IP is directed to the protocols that occur in the Transport Layer. The Transport Layer in the OSI reference model guarantees that the receiver gets the data exactly as it was sent.
 - *3 Network Layer* - The Network Layer manages connections across the network and isolates the upper layer protocols from the details of the underlying network. The Internet Protocol (IP), which isolates the upper layers from the underlying network and handles the addressing and delivery of data, is usually described as TCP/IP's Network Layer.
 - *2 Data Link Layer* - The reliable delivery of data across the underlying physical network is handled by the Data Link Layer.
 - *1 Physical Layer* - The Physical Layer defines the characteristics of the hardware needed to carry the data transmission signal. Features such as voltage levels, and the number and location of interface pins, are defined in this layer.
- <http://www.citap.com/documents/tcp-ip/tcpip006.htm>

WHERE DOES INTELLIGENCE LIE

- Smart Networks, Dumb Packets/Vehicles (Railroads, Telephone)
- **Smart Packets/Vehicles, Dumb Networks (Roads, Internet)**
- Important to resolve this in network design

NETWORK DESIGN VS. NETWORK GROWTH

- Network Design Problem (NDP) tries to determine "optimal" network according to some criteria (Z). - Normative
- E.g. Maximize Z, subject to some constraints.
- Network Growth Problem tries to predict actual network according to observed or hypothesized behaviors. - Positive

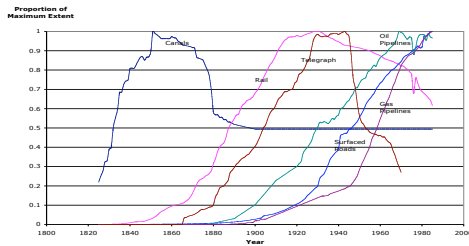
QUESTIONS

- Why do networks expand and contract?
- Do networks self-organize into hierarchies?
- Are roads an emergent property?
- Can investment rules predict location of network expansions and contractions?
- How can this improved knowledge help in planning transportation networks?
- To what extent do changes in travel demand, population, income and demographic drive changes in supply?
- Can we model and predict the spatially specific decisions on infrastructure improvements?

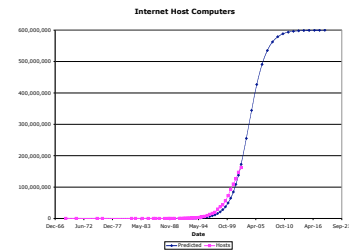
NETWORK GROWTH

- Depends on **existing and forecast** transportation demand
- Depends on **existing** transportation supply
- Network can be viewed as output of a production function: $N = f(D, S)$

S-CURVES



S-CURVE: INTERNET (HYPOTHESIZED)



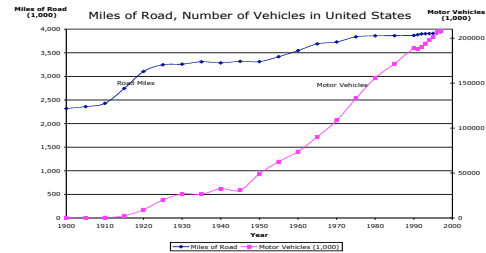
LIFE CYCLE MODEL

Where:

$$\frac{f}{1-f} = e^{at+b}$$

f = fractional share of technology (technology's share of final market share)
 t = time
 a, b = model parameters

MACROSCOPIC VIEW



NETWORKS IN MOTION

- [UK Turnpikes 1720-1790](#)
- [UK Canals 1750-1950](#)
- [Twin Cities 1920-2000](#)
- [Twin Cities 1962-2000](#)

HOW NETWORKS CHANGE WITH TIME

- Nodes: Added, Deleted, Expanded, Contracted
- Links: Added, Deleted, Expanded, Contracted
- Flows: Increase, Decrease

City	Feature in dominant city
New York-Northern New Jersey-Long Island, NY-NJ-CT-PA	harbor
Los Angeles-Riverside-Orange County, CA	harbor
Chicago-Gary-Kenosha, IL-IN-WI	harbor, river/canal connections to Mississippi
Washington-Baltimore, DC-MD-VA-WV	harbor (Baltimore), capital (Washington)
San Francisco-Oakland-San Jose, CA	harbor
Philadelphia-Wilmington-Atlantic City, PA-NJ-DE-MD	harbor
Boston-Worcester-Lawrence, MA-NH-ME-CT	harbor
Detroit-Ann Arbor-Flint, MI	strategic crossing
Dallas-Fort Worth, TX	trading post/crossing of Trinity River
Houston-Galveston-Brazoria, TX	harbor
Atlanta, GA	rail terminus
Miami-Fort Lauderdale, FL	rail terminus, resort
Seattle-Tacoma-Bremerton, WA	harbor
Cleveland-Akron, OH	river/canal terminus, Great Lakes port
Minneapolis-St. Paul, MN-WI	St. Anthony Falls on Mississippi River, most northerly navigable location
Phoenix-Mesa, AZ	site of an ancient Native American irrigation system, Salt River
San Diego, CA	harbor
St. Louis, MO-IL	confluence of Missouri and Mississippi rivers
Pittsburgh, PA	confluence of Allegheny and Monongahela rivers with Ohio river
Denver-Boulder-Greeley, CO	gold discovery at the confluence of Cherry Creek and the South Platte River (resource extraction)

THE NODE FORMATION PROBLEM

CHRISTALLER'S CENTRAL PLACE THEORY (CPT)

- How are urban settlements spaced, more specifically, what rules determine the size, number and distribution of towns.
- Christaller's model made a number of idealizing assumptions, especially regarding the ubiquity of transport services, in essence, assuming the network problem away.
- His world was a largely undifferentiated plain (purchasing power was spread equally in all directions), with central places (market towns) that served local needs.
- The plain was demarcated with a series of hexagons (which approximated circles without gaps or overlaps), the center of which would be a central place.
- However some central places were more important than others because those central places had more activities.
- Some activities (goods and services) would be located nearer consumers, and have small market areas (for example a convenience store) others would have larger market areas to achieve economies of scale (such as warehouses).

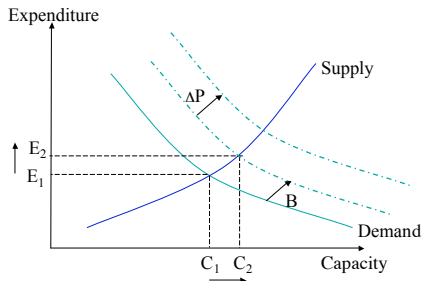
CENTRAL PLACE & NETWORK HIERARCHY

- Network Hierarchy is much like Central Places (Downtown Minneapolis, Suburban Activity Centers (e.g. Bloomington, Edina, Eden Prairie), Local Activity Centers (e.g. Dinkytown, Stadium Village, Midway), Neighborhood Centers (4th Avenue & 8th Street SE).
- Central Places occur both within and between cities.
- Hierarchy: Minneapolis-St. Paul; Duluth, St. Cloud, Rochester; Morris, Brainerd, Marshall, etc.; International Falls, etc.

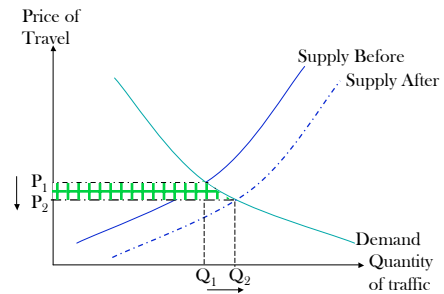
LINK EXPANSION AND FORMATION MODEL

- Construction or expansion of a link is constrained by the decisions made in past.
- Capacity increases often aim to decrease congestion on a link or to divert traffic from a competing route
- Some cases in anticipation of economic development of an area.
- Finite budget constrains the number of links developed
- Supply curve more inelastic with time

SUPPLY-DEMAND CURVE



INDUCED DEMAND & CONSUMERS' SURPLUS

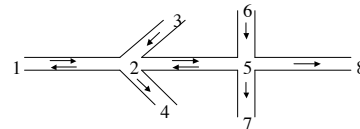


DATA

1. Network data from Twin Cities Metropolitan Council
2. Average Annual Daily Traffic (AADT) data from Minnesota Department of Transportation: Traffic Information Center
3. Investment data from:
 - Transportation Improvement Program for the Twin Cities
 - Hennepin County Capital Budget.
4. Population of MCD's from Minnesota State Demography Center

ADJACENT LINKS IN A NETWORK

- Divided into two categories: supplier links and consumer links
- For link 2-5: 1-2, 3-2 are supplier links and 5-7, 5-8 are consumer links



PARALLEL LINK IN A NETWORK

- Bears brunt of traffic if the link were closed
- Fuzzy logic using the modified sum composition method
- Four attributes defined by:
 - Para - 1 - (angular difference) / 45
 - Perp - 1 - a*(perpendicular distance) / length of link
 - Shift - 1 - b*(sum of node distances) / length of link
 - Comp - 1 - c*(lratio-1) (a=0.4, b=0.25, c=0.5)

COST FUNCTION

$$E_{ij} = f(L_{ij} * \Delta C_{ij}, N, T, Y, D, X)$$

- E_{ij} - cost to construct or expand the link
- $L_{ij} * \Delta C_{ij}$ - lane miles of construction
- N - dummy variable to new construction
- T - type of road
- Y - year of completion - 1979
- D - duration of construction
- X - distance from the nearest downtown

HYPOTHESIS

- Cost increases with lane miles added
- New construction projects cost more
- Cost is proportional to the hierarchy of the road
- Cost increases with time
- Longer duration projects cost more
- Cost is inversely proportional to the distance from the nearest downtown

RESULTS OF COST MODEL

Variable	Coef.	P> t
Lane-miles added	0.47	0.00*
New construction	0.40	0.03*
Interstate highways	1.43	0.00*
State highways	0.52	0.03*
Log (Year-1979)	0.76	0.00*
Log (Duration)	0.36	0.01*
Distance from nearest downtown	-0.03	0.04*
Constant	5.45	0.00*

* Significance at 95% confidence interval

EXPANSION MODEL: HYPOTHESIS

The following factors favor link expansion:

- Congestion on a link
- Increase in Vehicle Kilometers Traveled (VKT)
- Higher budget for a year
- Increase in capacity of downstream or upstream links
- Increase in population

The following factors deter link expansion:

- High capacity
- Length of the link
- Parallel link expansion
- Cost of expansion

RESULTS: LINK EXPANSION

Variable	Hypo.	Interstate	TH	CSAH
Cij	-S	-2.06E+00*	-8.15E+00*	
Lij	-S	-2.62E+00*	-2.28E+01*	-5.52E-01
Qij/Cij	+S	-2.50E-05*	-9.30E-05*	1.97E-04*
Qp/Cp	+S	1.57E-05*	1.05E-05	-1.99E-05
A02(Qij*Lij)	+S	3.98E-04*	1.67E-03*	2.81E-03*
A24(Qij*Lij)	+S	5.10E-04*	4.89E-04	2.72E-03*
A46(Qij*Lij)	+S	5.10E-04*	4.89E-04	2.72E-03*
A68(Qij*Lij)	+S	-5.96E-04*	4.54E-03*	3.80E-03*
Eij	-S	-3.21E-09**	-8.18E-10	6.84E-10
B	+S	4.38E-06*	7.32E-05*	1.07E-05*
Y	-S	-1.09E+00*	-1.17E+00*	8.37E-02
X	+S	-6.23E-03	1.13E-01	5.19E-02
Qij+Qik	+S	1.09E-05*	2.37E-05*	-1.71E-05*
Chi+Cjk- Cij	-S	-6.07E-01*	-5.49E-01*	5.43E-02
P	-	2.56E-06*	1.28E-05*	-1.63E-05*
ΔP	+S	2.54E-04*	1.17E-03*	-1.40E-04*

No. of Obs: 10986 LL = -293.92 Pseudo R2 = 0.46
 No. of Obs: 17926 LL = -41.34 Pseudo R2 = 0.61
 No. of Obs: 6533 LL = -302.94 Pseudo R2 = 0.29

* Significance at 90% level

RESULTS: EXPANSION MODEL

- Most of the hypotheses are corroborated
- Change in demand favors expansion, consistently
- Higher cost decreases probability of expansion while higher budget increases the same
- Probability of a two-lane expansion over one-lane expansion declines with time
- Lower hierarchy roads depend on budget but not on cost
- Interstate links showed significant variation in response to variables length and change in VKT over two years

NEW CONSTRUCTION

- Follow different criteria than expanding existing links
- Choice made in a network of possible construction sites
- Road type of the new link unknown
- Modeled in 5-year intervals due to few construction projects

Assumptions:

- Interchange is a single node
- New construction does not cross any existing higher class road
- Can cross lower level roads without intersecting
- Links of length between 200m and 3.2 Km only considered

NEW CONSTRUCTION MODEL

$$N_{ijt+1} = f(L_{ij}, C_p, L_p, Q_p/C_p, A, E_{ij}, B, Y, X, D)$$

Where:

N - New construction	A - Access measure
C - Capacity of the link	E - Cost of construction
L - Length of the link	X - Dist. from downtown
Q - Flow on the link	D - number of nodes in the area
Y - Year	ij - link in consideration
	p - parallel link

HYPOTHESIS: NEW LINK CONSTRUCTION

The following factors favor new link construction:

- High capacity of parallel link
- Congestion on parallel link
- Length of parallel link
- Higher budget
- Higher access score

The following factors deter new link construction:

- Cost of expansion
- Number of nodes in the area

RESULTS OF NEW CONSTRUCTION MODELS

Variable	Hypo.	Coefficient
Length of the link	-	-5.91E-01
Capacity of the parallel link	+S	-3.31E-01*
Length of the parallel link	+S	4.93E-01*
Congestion on parallel link	+S	-1.96E-05
Access measure	+S	4.24E-05*
Year	-S	7.31E-01*
Cost of construction	-S	-2.82E-01*
Budget	+S	5.68E-06*
Distance from downtown	+S	-1.21E-01*
No. of nodes in the area	-S	-6.32E-04
Constant		-6.09E+00*

Number of Observations: 89031
Logit LL = -473.19

* Significant at 90% confidence interval

RESULTS: NEW CONSTRUCTION

- Significantly depends on surrounding and alternate route conditions
- High capacity parallel link reduces need for a new link
- High dependence on the accessibility measure
- Highly connected areas require fewer new links
- Policy shift from expansion to construction

IMPLICATIONS

- Just as we could forecast travel demand, demographics, and land use, we can now forecast network growth.
- We can now understand the implications of existing policies (bureaucratic behaviors) on the shape of future networks.
- By forecasting future network expansion, we can decide whether or not this is desirable or sustainable outcome, and then act to intervene.

TURN IN SURVEY

AFTER 10 MIN BREAK

- Students who are assigned to computer lab, go there.
- Other students stay here.