This Week…
Feb 25, 27


DQ WEEK 7

Week 7 (Feb 25, 27)

Network Methodologies

GIS MARKETING LAB DUE

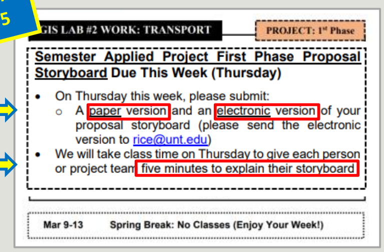
The Transportation and Logistics Domain: Supply Chain and Spatial Analytics
Rice and Hernandez (2017) Section 2.3 "Transportation"; Rodrigue, Comtois, and Slack (2006) Chapter 2 "Transportation Systems and Networks"*; Longley et al. (2005) Chapter 59 "Transportation GIS: GIS-T"; *[Church and Murray (2009) Chapter 9 "Coverage"]*; See all week 9 resources on the "Syllabus and Handouts" page

Week 7 Discussion Question Set Due This Week (Tuesday)

GIS Lab 5 (Marketing and Geodemographic Analysis) Due This Week (Thursday)

- The bases of spatial interaction
- JCPenney: A case study of the role of transportation and logistics in the modern corporation
- Modeling and analyzing transportation networks
- Further exploration of location-allocation methodological options
- GIS and transport routing

Next Week…
Mar 3, 5


GIS LAB #2 WORK: TRANSPORT

PROJECT: 1st Phase

Semester Applied Project First Phase Proposal Storyboard Due This Week (Thursday)

- On Thursday this week, please submit:
  - A paper version and an electronic version of your proposal storyboard (please send the electronic version to rice@unt.edu)
- We will take class time on Thursday to give each person or project team five minutes to explain their storyboard

Mar 9-13 Spring Break: No Classes (Enjoy Your Week!)

Transportation & Logistics

WEEK 7

Geography and Diverse Applications

This week: broadening our analytical perspectives

- Key point: attention to geography can benefit organizations of all kinds
  - Retail and services (such as we examined in our Denver and Portland GIS exercises):
    - Space and place are obviously important factors and must be considered in every business plan
  - But what do geographic concepts and applications look like for businesses in other sectors of the economy?

Geography and Diverse Applications

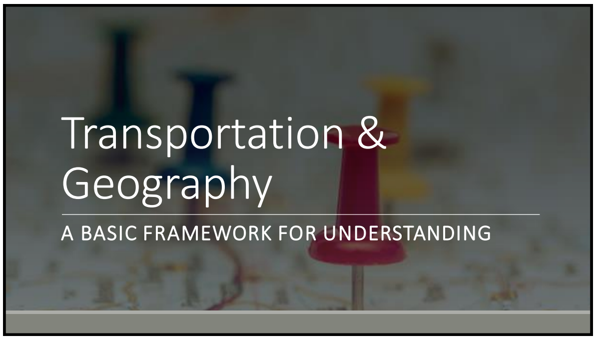
Transportation: An Inherently Geographic Industry

- Transportation represents a logical next venue for geographic application for us to explore
- Transportation exists because of geography
  - Supply of something in one place
  - Demand for that same thing in another place
- The modern transportation and logistics industry cannot function without careful analysis of places, supplies, demands, routes, and infrastructure

Geography and Diverse Applications

Transportation: An Inherently Geographic Industry

- A brief video interview gives us some initial insight into how and why one transportation company, Con-Way Freight, uses geographic data and analysis
- **Q:** What are the key location analytics applications and benefits mentioned in this short interview?



Transportation and Geography Basics

Ullman's three "bases of spatial interaction": how and why interaction between different places occurs

- 1. Complementarity
- 2. Transferability
- 3. Intervening Opportunity

Transportation and Geography Basics

1. Complementarity

- Something that one place has (a supply) is needed in another place (with a demand)
  - **Example:** a factory creates a supply of some product, but shipment will only occur from the factory if the product made in the factory is demanded in other places
  - **Q:** How might complementarity be used to explain spatial interactions involving an office complex (i.e. flows of people to and from the complex)?
  - **Note:** complementarity on its own is not sufficient for transport to occur

Transportation and Geography Basics

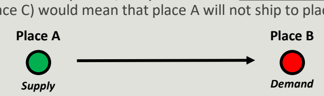
2. Transferability

- The thing that is supplied by one place and demanded in another place must be capable of being transported
  - **Example:** for a factory to ship a product to other places, that product cannot be destroyed by the transportation process
  - **Q:** When might transferability not be possible?
  - **Note:** transferability and complementarity on their own are not sufficient for transportation to occur

Transportation and Geography Basics

3. Intervening Opportunity

- Even with a supply in place A, a demand in place B, and the ability to ship between place B, the presence of a closer source of supply (place C) would mean that place A will not ship to place B



Transportation and Geography Basics

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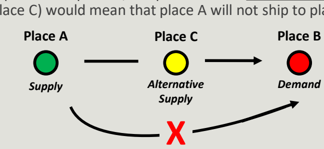


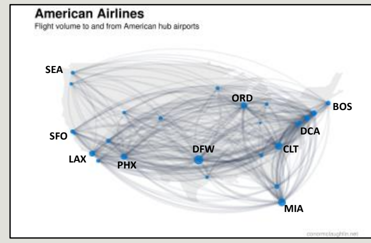
Transportation and Geography Basics

Ullman's "Bases" provide a key foundation for understanding <u>entire networks of interactions</u> among a system of places

- Let's consider a couple of examples…

The **American Airlines** domestic flight network map as of 2019 (flights among hub cities only)

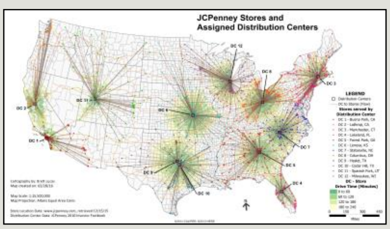
Q: Does Ullman's "Bases" relate to what is going on in this map?



http://conormclaughlin.net/2019/02/us-airline-flight-maps/

The **JCPenney** store and distribution center map

Q: What's the relevance of Ullman's "Bases" here?



Courtesy of Brett Lucas

Case of JCPenney

GEOGRAPHY, TRANSPORTATION, AND LOGISTICS

JCPenney

An excellent example of a business that has had to pay close attention to geography over the years

- JCPenney has had an operations network undergoing <u>significant evolution</u>, beginning with an initial store location in Kemmerer, Wyoming (1902)

JCPenney's initial store location

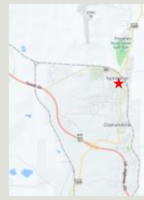
Very close to "the middle of nowhere"

JCPenney

By 1912, had 34 stores across the Rocky Mountain states

- **1941:** reached 1,600 stores (in all 48 states then existing)
- **1961:** first shopping center location
- **1963:** began catalog operation
- **1973:** peak store numbers reached, with 2,053 locations
- **1998:** launched e-commerce site

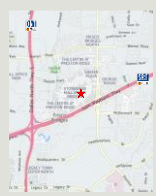
Kemmerer, Wyoming
"Mother Store"



La Grande, Oregon
"Main Street" store location (not unlike JCPenney's original location on Denton's Courthouse Square)

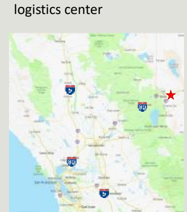
Courtesy of Brett Lucas

Stonebriar Mall
location in Frisco, Texas



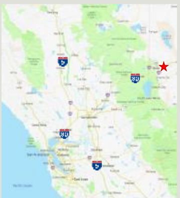
Big Box Store retail power center location in Conroe, Texas

Reno, Nevada
logistics center



Courtesy of Brett Lucas

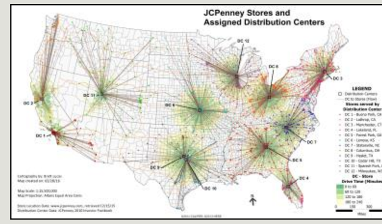
Reno, Nevada
logistics center



Courtesy of Brett Lucas

Q: What do you see as the challenges facing JCPenney and competing retailers?

What is the role for geographic analysis at JCPenney?



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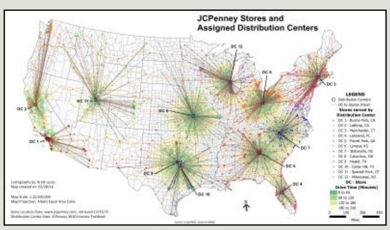
All of this raises the question of <u>what geographic analytical methodologies are available</u> to help JCP with future store and logistical network decisions



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Discover the power of ideas

Network Analytical Methodologies

GEOGRAPHY, TRANSPORTATION, AND LOGISTICS

Network Methodologies

We can identify a series of approaches to network, flow, and location analysis that can each be further explored to assist businesses in making sound operational decisions
- 1. Modeling a network as a graph
- 2. Location-allocation analytical choices
- 3. GIS and routing solutions

Modeling a Network as a Graph

BASIC CONCEPTS

Modeling a Network as a Graph

To set up for further analysis, we need a way of capturing the essential characteristics of a transport network of interest

- The following explains a logical and powerful way of doing this, and introduces some of what is possible once we have encoded the network in this way

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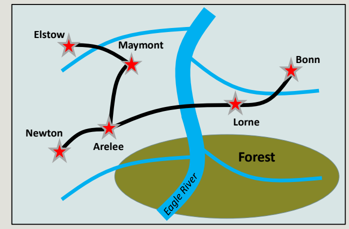
A simple **transport network** with

- 6 towns
- 5 connecting highways

Imagine a Real-World Transport Network

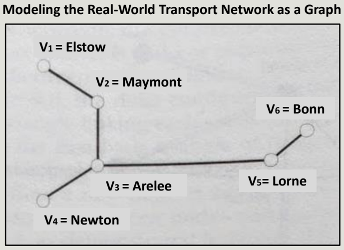


Modeling the Real-World Transport Network as a Graph

The network has **6 vertices** (towns) and **5 connecting links**

Vertices = towns/places

Q: What do you see as the value of representing a real-world network like this? Any apparent issues?

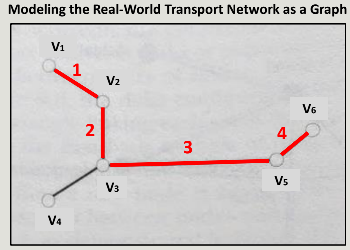


Sample Network Graph Illustrations From: E.J. Taaffe, H. Gauthier, and M. O'Kelly (1996) *The Geography of Transportation* (2nd Edition).

Modeling the Real-World Transport Network as a Graph

The network has **6 vertices** (towns) and **5 connecting links**

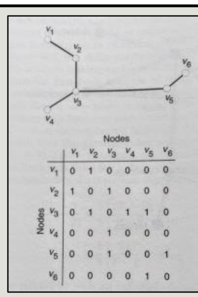
The **diameter** of the network is the greatest number of links necessary to travel completely across it (in this case, diameter = 4)



Sample Network Graph Illustrations From: E.J. Taaffe, H. Gauthier, and M. O'Kelly (1996) *The Geography of Transportation* (2nd Edition).

The same transport network modeled as a **connectivity matrix**

0 = no connection between nodes
1 = connection between nodes



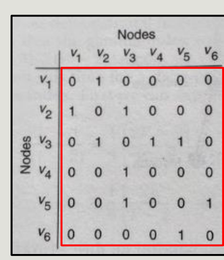
Nodes

	v_1	v_2	v_3	v_4	v_5	v_6
v_1	0	1	0	0	0	0
v_2	1	0	1	0	0	0
v_3	0	1	0	1	1	0
v_4	0	0	1	0	0	0
v_5	0	0	1	0	0	1
v_6	0	0	0	0	1	0

Note: it is possible to generate related matrices that can be used in similar but distinctive ways

Example: create a flow matrix, representing amount of traffic traveling on each network link (e.g., number of cars/hour, or number flights/day)

Another: create a distance or travel time matrix, representing the distance/time separating each node



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v_4	0	0	1	0	0	0
v_5	0	0	1	0	0	1
v_6	0	0	0	0	1	0

Numbers here would change from zeros & ones to actual flow values (e.g. cars per hour)

Example: Travel Times Matrix for Key Points in New York City

	A	B	C	D	E	F	G	H	I
1	Name	Citi Field	Empire State Building	Grand Central	Javits Center	JFK Airport	Laguardia Airport	Madison Square Garden	Museum of Modern Art
2	Citi Field	--	26.5	27.0	41.8	20.7	6.9	30.0	31.0
3	Empire State Building	25.5	--	10.7	20.8	36.9	22.9	5.0	10.6
4	Grand Central	22.3	6.5	--	20.7	33.7	19.7	9.8	10.2
5	Javits Center	28.5	9.0	10.1	--	39.9	25.9	8.1	8.6
6	JFK Airport	23.1	41.7	42.2	57.0	--	25.5	45.2	46.2
7	Laguardia Airport	7.7	23.5	24.0	38.8	23.0	--	27.0	28.0
8	Madison Square Garden	27.5	6.7	12.0	15.9	38.9	24.9	--	10.5
9	Museum of Modern Art	26.3	10.6	7.0	21.7	37.7	23.7	12.6	--
10	Museum of Natural History	28.0	16.9	17.5	23.2	43.4	25.3	16.0	11.0
11	Penn Station-New York	25.1	4.3	10.2	17.5	36.5	22.5	1.6	9.5
12	Radio City Music Hall	25.9	9.3	5.7	20.7	37.3	23.3	11.5	5.7
13	Yankee Stadium	20.1	30.2	30.1	34.0	35.4	17.3	29.3	24.5

Travel Time (Minutes) | Distance (Miles)

Two transportation matrix types/applications

1. Flow Matrix: representing amount of traffic traveling on each network link (e.g., number of cars/hour, or number flights/day)

2. Distance/Time Matrix: representing amount of distance separating each node

Note: we would interpret these two matrices differently (**Q:** Why?)

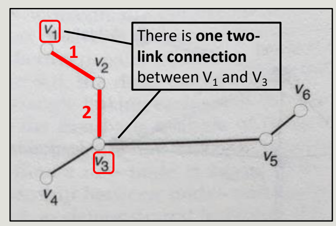
Flow matrix: higher values mean a closer relationship between places

Distance matrix: lower values mean a closer relationship between places

Once we have the connectivity matrix constructed, we have a foundation that makes numerous other transportation analyses possible

Nodes	V_1	V_2	V_3	V_4	V_5	V_6
V_1	0	1	0	0	0	0
V_2	1	0	1	0	0	0
V_3	0	1	0	1	1	0
V_4	0	0	1	0	0	0
V_5	0	0	1	0	0	1
V_6	0	0	0	0	1	0

One example: in "squaring" the original connectivity matrix, we gain a new matrix that provides the total number of two-link (one-stop) connections between all nodes in the network



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V_4	0	0	1	0	0	0
V_5	0	0	1	0	0	1
V_6	0	0	0	0	1	0

C: no-stop (direct) connections

→

	V_1	V_2	V_3	V_4	V_5	V_6
V_1	1	0	1	0	0	0
V_2	0	2	0	1	1	0
V_3	1	0	3	0	0	1
V_4	0	1	0	1	1	0
V_5	0	1	0	1	2	0
V_6	0	0	1	0	0	1

C^2: two-link, one-stop connections

Q: What's the value in tabulating the two-link connections in a transportation network?

A key transportation geography analytical tool: the total accessibility matrix ("T-matrix")

A tabular summary of all of the direct (non-stop) and indirect (one or more stop) routes that exist in the network

- For the entire network
- For each place in the network

The T-matrix allows us <u>two capabilities</u>:

1. Evaluate the accessibility of individual network nodes (locations in the network)

This allows us to identify <u>strategic places</u> in the network: places well-positioned to serve network demand

Which are the most accessible places to locate something like a warehouse or other facility?

The T-matrix allows us <u>two capabilities</u>:

2. Measure the accessibility options provided by the entire network

This allows us to identify all <u>possible ways of getting around</u> the network

More options = better, so how many options do we actually have?

<u>Key note</u>: real-world networks are much more complex than the simple network example we were examining

- However, the network modeling methods introduced here provide good insights into <u>opportunities</u> and <u>vulnerabilities</u> in any given network
- Let's look into a brief case study to illustrate some potential applications

Sample Case Study: Ohio Highway Network Configuration Analysis

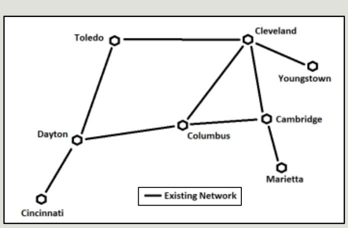
Interstate highways are a crucial element of the national transportation infrastructure that supports the American economy, society, and defense

Important task: evaluate the interstate highway network to search for needed improvements

Sample Case Study: Ohio Highway Network Configuration Analysis

For our analysis, we can represent this real-world network in graph form

Question: If a <u>route addition</u> were to be made to this network, which one would yield the most substantial accessibility improvement?



To start, we need to understand the form of the network as it stands before any change is made.

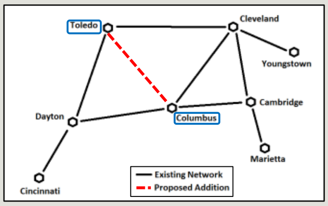
Here is the **T-Matrix** as we have defined it (total accessibility matrix).

This matrix shows that the current Ohio interstate highway network includes **254 total links.**

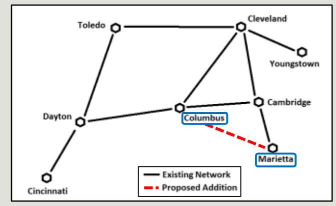
	TOL	CLE	YNG	CAM	MAR	COL	CIN	DAY	TOTAL	RANK
TOL	2	7	1	3	1	4	3	6	**27**	**6**
CLE	7	6	5	8	2	10	4	4	**46**	**2**
YNG	1	5	1	2	1	2	1	2	**15**	**7**
CAM	3	8	2	5	4	8	3	4	**37**	**3**
MAR	1	2	1	4	1	2	1	1	**13**	**8**
COL	4	10	2	8	2	8	7	9	**50**	**1**
CIN	3	4	1	3	1	7	4	6	**29**	**5**
DAY	6	4	2	4	1	9	6	5	**37**	**3**

Grand Total: 254

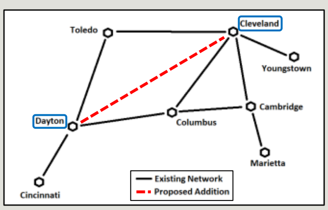
One proposed network link addition: **Toledo-Columbus**



Another proposed network link addition: **Columbus-Marietta**



A final network link proposal: **Dayton-Cleveland**



To assess the network impacts of each of the three proposed additions, we recalculate the T-Matrix in each case, and compare the total accessibility of each potential network.

	Original Network
T-Matrix Total	254

Total routes in original network

To assess the network impacts of each of the three proposed additions, we recalculate the T-Matrix in each case, and compare the total accessibility of each potential network.

Completion of the T-Matrix analysis shows the **Cleveland-Dayton** option has the biggest impact on total accessibility, compared to the original network.

Total Route Options With Network Additions

	Original Network	Cleveland-Dayton Addition	Columbus-Marietta Addition	Toledo-Columbus Addition
T-Matrix Total	254	348	318	338

This result does not mean that Cleveland-Dayton is the specific network extension that should be built, as this analysis does not deal with **cost**.

However, from a user-benefit perspective, this is the leading option in terms of interstate highway network **service improvement**.

Total Route Options With Network Additions

	Original Network	Cleveland-Dayton Addition	Columbus-Marietta Addition	Toledo-Columbus Addition
T-Matrix Total	254	348	318	338

Location-Allocation Solution Options

BASIC APPLICATIONS

Location-Allocation Solution Options

Location-allocation modeling simultaneously and optimally

- 1. Locates a series of specific service-providing facilities (a set of schools, hospitals, police stations, stores in a chain, delivery depots)
- 2. Allocates demand for the service to the facilities from across an extended region (what geographic area does each facility from #1 serve?)

One key fact we need to recognize is that there any many potential routes to solving this general form of a location problem, coming from the basic question of what is "optimal"?

Location-Allocation Solution Options

There are three principal approaches to solving the basic location-allocation problem

- 1. *P*-median problem (PMP)
- 2. Maximal covering location problem (MCLP)
- 3. Set covering location problem (SCLP)

1. *P*-median problem

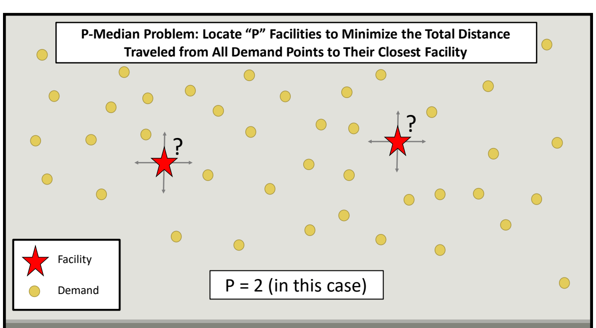
The PMP is the most general and best-known formulation of the location-allocation methodology

Objective: locate *p* facilities ("*p*" is a number you set) to minimize the total distance traveled by all customers to visit their closest service provider

Focus: maximize the overall efficiency of an entire service provision system

- Such as a school system, a hospital network, a chain of grocery stores…

Q: what could be sacrificed when we aim to maximize the overall efficiency of a large system?



1. *P*-median problem

The primary issue with the PMP is that there are no guaranteed service standards

- To make things work well for the system as a whole, some customers may not be served well at all
- **Example:** while overall distance traveled is minimized for everyone, we might find a small number of customers who need to travel excessively long distances (for services like education where students travel to the school)
- **Or:** we might find a small number of customers facing long service waits (for services like air conditioning repair that are delivered to the client)

1. *P*-median problem

Another PMP issue: you need to have some outside way of determining how many service facilities are appropriate

- How many are needed?
- Or maybe the key question is how many can you afford to build/operate?
- If you don't know this number, this is a problem with PMP application: this facility information is a required PMP input

2. Maximal covering location problem

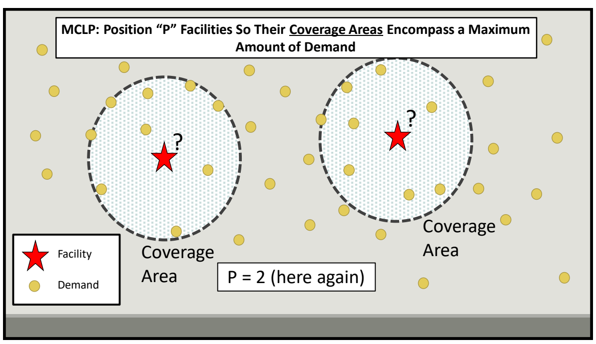
The MCLP is intended to address some of the shortcomings of the PMP

Objective: still locating *p* facilities, but this time the goal is to maximize the number of customers covered for service within a set service standard

- The improvement: it defines the service level you want to achieve

What does this mean?

- *One example:* maximize the number of houses within a 15-minute walk of their nearest school
- *Another:* maximize the number of buildings within a 5-minute drive of the closest fire station



2. Maximal covering location problem

Q: Do you see any potential issues with application of the MCLP?

Key downfalls:

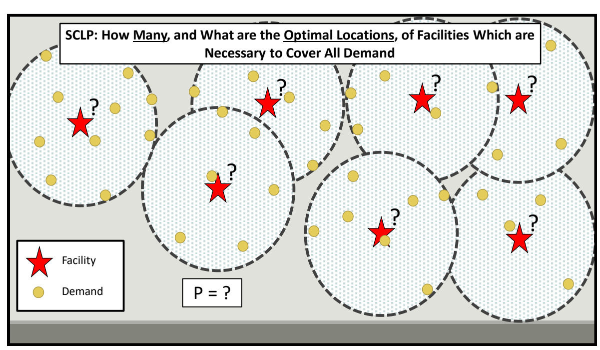
- 1. It is still possible to provide bad service to a minority of customers (those outside of the coverage area), even with the maximal coverage goal and definition of a target coverage standard
  - Inconvenient travel times/distances
  - Long wait times for service
- 2. You still need to decide in advance on the appropriate number of facilities to serve the region

3. Set covering location problem

The SCLP addresses both of the major location issues we have seen so far

Objective: determine the number of facilities needed to cover a region to achieve a given service standard for every customer

- How many police stations are necessary to ensure no house is more than a 10 minute drive away from police help?
- How many water pumping stations are necessary to ensure every house in the city is no more than 4 miles from a station?



3. Set covering location problem

In this way, the SCLP defines both

- 1. A service standard to be implemented
- 2. The number of facilities needed to achieve the standard

Q: Are there any issues or shortcomings that you can see with the SCLP?

- The SCLP gives no flexibility in plans to serve isolated customers that are very expensive to serve on their own
- The SCLP gives no information to help you assess and set your service standard

The following is a set of MCLP location-allocation results I provided to support one small part of the Canadian healthcare system in the mid-1990s

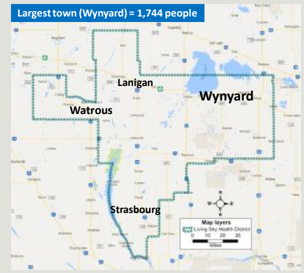
Location-Allocation Case Study Analysis: Canada's Living Sky Health District (Pop. 27,809)

Situation: large region of small towns and farms with a population in need of routine, preventative health care services

Problem: Locate the appropriate number of health clinics to efficiently serve the population distributed across the district

1. What is the appropriate number of clinics to serve the region?
2. Where should these clinics go?

Solution: use location-allocation modeling to inform clinic location decisions

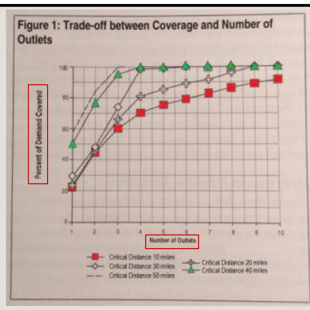


Location-Allocation Case Study Analysis: Canada's Living Sky Health District (Pop. 27,809)

Select the **MCLP** approach for strategic use here to gain the maximum amount of useful information to support the healthcare decision-making team

Graph here: illustrates balance between number of clinics and service provided

1. More clinics, higher costs (bad)
2. But also recognize that using more clinics yields better coverage (good)



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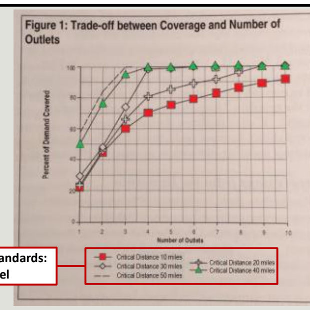
Different critical distances /service standards: target distance for patient travel



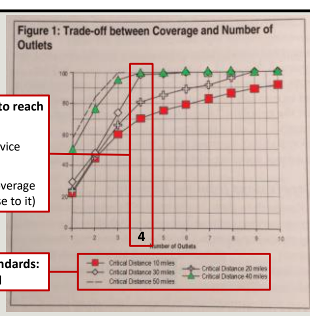
Location-Allocation Case Study Analysis: Canada's Living Sky Health District (Pop. 27,809)

At around the 4-clinic level, we appear to reach a critical service point

- For all critical distances considered, service coverage provided is at 70% or greater
- For three critical distance standards, coverage has actually reached 100% (or very close to it)

2. But also recognize that using more clinics yields better coverage (good)

Different critical distances /service standards: target distance for patient travel



MCLP: produces a table reflecting where health clinics should go for a given service standard choice/clinic investment

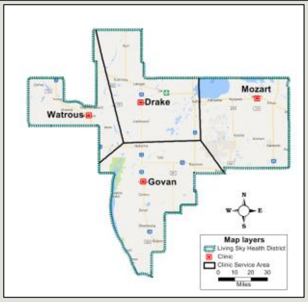
Table: Critical Distance (Miles), Number of Clinics, and Coverage (%)

CHCs	10	20	30	40	50
1	Wynyard 22.3%	Mozart 23.5%	Drake 29.3%	Drake 50.3%	Lockwood 57.5%
[illegible]	[illegible]	[illegible]	Drake & Govan 47.9%	Drake & Mozart 76.8%	Lockwood & Mozart 83.9%
3	Wynyard, Watrous, & Lanigan 60.0%	Mozart, Watrous & Lanigan 66.0%	Drake, Govan & Mozart 73.9%	Drake, Mozart & Govan 95.3%	Wynyard, Manitou Beach, & Strasbourg 99.89%
4	Wynyard, Watrous, Lanigan & Strasbourg 70.2%	Mozart, Watrous, Lanigan & Strasbourg 80.8%	Drake, Mozart, Govan & Watrous 98.6%	Mozart, Lanigan, Strasbourg, & Watrous 100%	Wynyard, Lanigan, Watrous & Strasbourg 100%

Solution for 30 mile coverage target and investment of 4 health clinics

Location-Allocation Case Study Analysis: Canada's Living Sky Health District (Pop. 27,809)

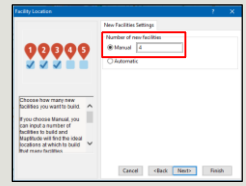
Final Solution: 4 clinics, 30 mile target distance service area standard, with clinic locations and service areas as defined on this map



Maptitude and location-allocation

Note that Maptitude provides some great location-allocation functionality in its "Facility Location" tool

Number of new facilities (<u>Manual</u> Option) gives access to
- p-median
- MCLP

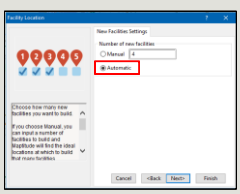


Maptitude and location-allocation

Note that Maptitude provides some great location-allocation functionality in its "Facility Location" tool

Number of new facilities (<u>Automatic</u> Option) accesses
- SCLP

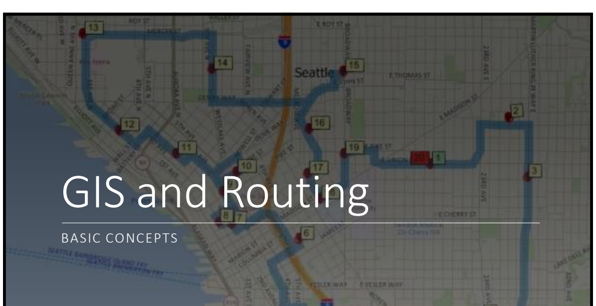
We will get some practical exposure to these Maptitude capabilities in our Transportation GIS Exercise next week



Overall: location-allocation methods

1. Location-allocation provides a suite of solution approaches that each have their own inherent strengths and weaknesses

2. The location analyst must understand each approach and be able to select the one approach that best fits their situation



GIS and Routing

BASIC CONCEPTS

GIS and Routing

We have already seen how networks can be effectively encoded to capture their essential elements

It is a natural next step to transition from modeling <u>overall network characteristics</u> to solving for the <u>most efficient routing</u> to follow through a network

Since the number of potential network routing applications and solutions is great, we will focus on one of the <u>most major and widely-used</u> network transportation problems: the **"traveling salesman problem"** (TSP)
- This <u>gender-specific name</u> is the search term you will need to use if you wish to find more information on previous applications of this analysis going back to the 1960s

GIS and Routing

The TSP is one of the most important problems that can be solved, if for no other reason than many people solve some variation of this problem everyday

Common issue: you need to get from point A to point B, but you also have some other stops to make along the way

GIS and Routing

Q: What are some elements that enter into your thinking when you need to plan your way through a real-world situation like this?

- This is actually a very complex problem to solve, with many factors to take into account

GIS and Routing

A definition of the details of the available TSP solution methods goes beyond the time we have available

However, we can say a few things about the TSP itself, as well as software tools for determining a TSP solution

GIS and Routing

The core TSP problem:

- 1. Your start and end points are known (and are often the same place, such as your home, your workplace, or some temporary base)
- 2. The intermediate stops along the way are also known
- 3. The order in which the stops are made must be decided
- 4. The route you will follow from each stop to the next must also be decided

Example: TSP Solution for One Vehicle and a Predefined List of Stops in Central Seattle

Example: TSP Solution for <u>3</u> <u>Vehicles</u> and a <u>Complex</u> <u>List of Stops</u> to Divide Among the Vehicles

GIS and Routing

TSP solution considerations

- 1. The only reliable way of guaranteeing a 100% optimal solution is to <u>try all possible stop/route combinations</u> (time & computation intensive)
- 2. This "complete enumeration" method only works well up to a <u>certain problem size</u> (often around 10 stops)
- 3. Going beyond that, transportation analysts have developed a series of <u>heuristic algorithms</u> that essentially make good estimates and narrow in on a solution from there