Network Models

SIE 510
Spring 2009

From Miller, H. and S. Shaw. 2001. Geographic Information Systems for Transportation. Oxford:Oxford University Press.

January 29, 2009

GIS Models

The Natural System ⟷ The Formal System

Part of the real world to be analyzed

Description of entities and their relations in the real world

Representation of the real world as a model in the GIS

An abstraction of the natural system which represents part of the real world

GIS Models

The Natural System ⟷ The Formal System

Transportation systems

Utility networks

Stream networks

Geneological networks

Description of entities and their relations in the real world

Representation of the real world as a model in the GIS

GIS-T Data Models

Principles are generalizable to networks in other application domains.

Problem of disconnect between the real world entities (of transportation and transit systems) and relative simplicity of GIS data models.

Network Models

Digital representation of a network supports a variety of applications

Objectives

- Find connected paths through a network(s)
- Estimate flows, costs of moving through, or accumulating resources in a network
- Manage/analyze parts of the network or assets associated with the network

Requires representation of topology, geometry, and semantics of the network

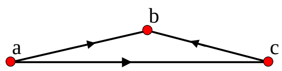
Network Model Topics

- Graph theory as underlying mathematical model
- Network representation
- Linear referencing systems
- Dynamic segmentation

Networks and Graph Theory

Graph theory provides the mathematical framework and abstract model for networks

Graph components



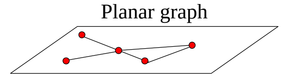
- Vertices – uniquely identified, represent members of a set
- Edges – represent logical relationships among members of the set
- Edges are *ordered* pairs of vertices (e.g. ab, cb, ac)

  directed edge – relation applies in one direction

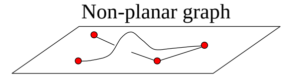
  undirected edge – relation applies in both directions

Networks and Graph Theory

Planar graph



Non-planar graph

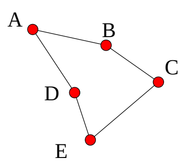


Embedded in a Euclidean plane, requires a vertex at every edge crossing, creates subdivisions of the plane

Does not require vertices at edge crossings, exists independently of any plane

Networks and Graph Theory

Graph theory focuses just on connectivity



	A	B	C	D	E
A	0	1	0	1	0
B	1	0	1	0	0
C	0	1	0	0	1
D	1	0	0	0	1
E	0	0	1	1	0

Network

- Network – graph for explicitly representing interaction - connected set of nodes and links
- Nodes – vertices representing origin, termini or relays, uniquely identified
- Links – edges representing conduits for flow between nodes, identified by labeled node pairs, for a directed graph the node order is significant

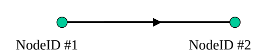
Networks can accommodate weights that represent unit cost of flow for a link

Network Models

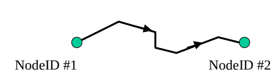
- graph theory aims at the abstraction of a network
- a network data model aims to provide an accurate representation of a network as a set of links and nodes.
- the topology of a network data model should be as close as possible to the real world structure it represents.

Network model components

- **Directed Link:** a topological straight line connection between two ordered nodes



- **Directed chain** – a directed link with intermediate shape points between two ordered nodes



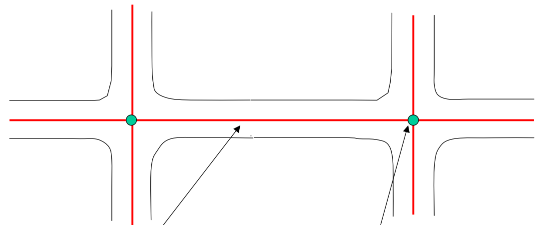
Network representation of transportation systems

- Transportation systems typically represented as directed networks
- Transportation system often partitioned into modal specific sub-networks

  Roadway, subway, air, rail, bus

- Often stored as separate networks with transfer links to represent connections

Road network representation

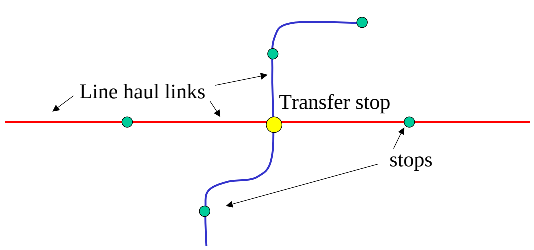


Links correspond to streets or roads

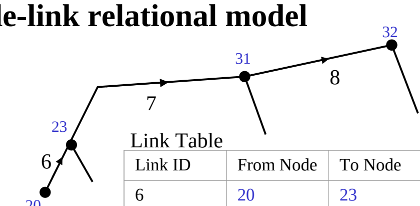
Nodes correspond to street intersections

Generalized cost function represents the unit cost to traverse a link

Transit network representation



Node-link relational model



Link Table

Link ID	From Node	To Node	Length
6	20	23	22
7	23	31	86
8	31	32	69

Node Table

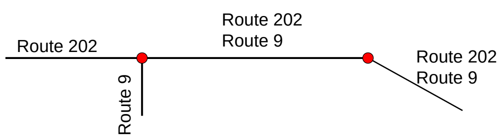
Node ID	X	Y
20	235.00	420.00
23	250.11	436.00
31	324.05	460.35
32	410.65	472.80

Relational model for node-link consists of link and node relations

Weaknesses of Planar Network

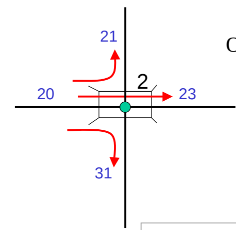
Most GIS require planar embedding of the node-link model

- Planar embedding forces nodes at all intersections
  Does not account for overpasses, underpasses, or ramps
- Assumes links are homogenous – an attribute is constant over a link
- Limited support for one to many and many to many relations



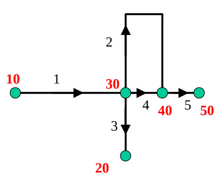
Turn Table Representation

Addition of a turntable relation addresses planar embedding limitation



Over pass – under pass situation

Node ID	From Arc	To Arc	Impedance
2	20	21	-1
2	20	23	0
2	20	31	-1



Link Table

Link-ID	From-Node	To-Node
1	10	30
2	30	40
3	30	20
4	30	40
5	40	50

Turn Table

Node-ID	From-link	To-Link	Impedance
30	1	3	5
30	1	4	10
30	1	2	-1
30	1	1	-1
30	4	2	-1
30	4	3	-1
30	4	1	-1

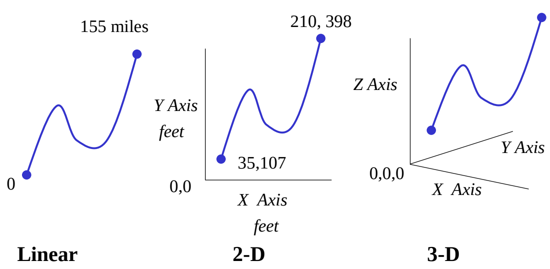
Node Table

Node-ID	attributes
10	
20	
30	
40	
50	

Spatial Referencing Systems

- A spatial reference system defines the parameters and rules to situate a measurement in space.
- The essential parameters for any spatial reference system are an origin and units.
- These are the required parameters for a linear spatial referencing system.

Spatial Referencing Systems



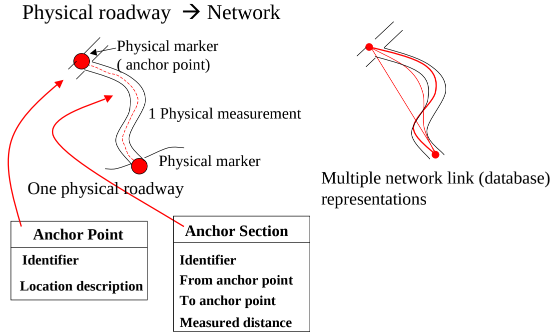
Linear Referencing Systems

Components

- Datum – set of objects with directly measured locations
- Network - digital spatial representation of nodes and links
- Linear referencing method (LRM) – method to determine a position within the network using a defined path and an offset distance along the path

Linear reference system relationships

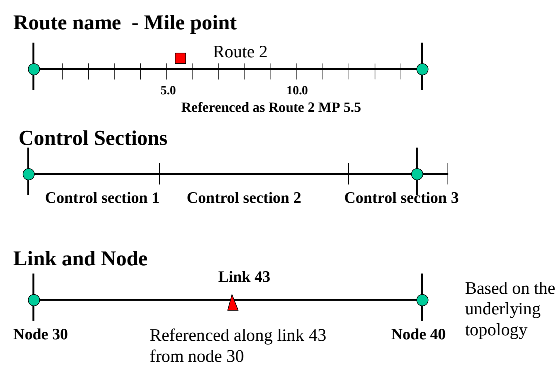
Physical roadway → Network



Linear Datum

Linear Referencing Methods

Indicate a distance from an origin in some units



Linear Referencing Systems

Widely used by Departments of Transportation since distances along roads were easier to collect than 2D positions and most assets are assumed to be on the road.

- Often collected on-road by Distance Measuring Instrument (DMI)
- Easy to report on-road attributes (e.g. accident ½ mile south of Milepost 153 on I-95)
- Can be easily understood by users (e.g. ambulance driver)
- Changing with the growing use of GPS

Dynamic segmentation

Segmentation of a network model at run time based on sets of linearly referenced events (discrete or interval).

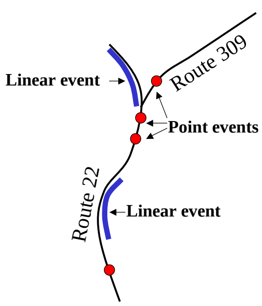
Event: an attribute associated with some measured length of a route or with a single location on a route

Allows multiple sets of attributes to be associated with different segments of the network

- Removes the need for a set of spatial objects for each attribute.
- Creates attribute based objects as needed.

Dynamic segmentation

Supports the association of "events" with measured positions along a transportation network



Point events

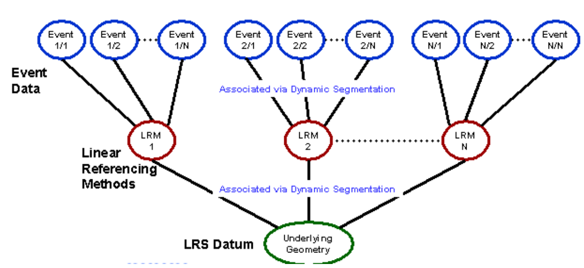
Accident event coded as: Route 22, Milepost 147.5

Linear events

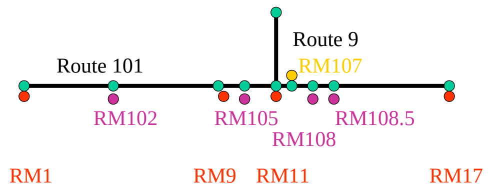
Passing zone coded as Route 22, Milepost 126.125 to Milepost 134.25

Continuous events

Associated with an entire route, only note where the value changes – speed limits



Spatial object for each attribute

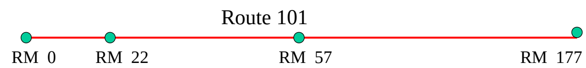


Multiple sets of linearly referenced events

Without dynamic segmentation, each event requires a node on the segment to indicate beginning and end of an attribute value

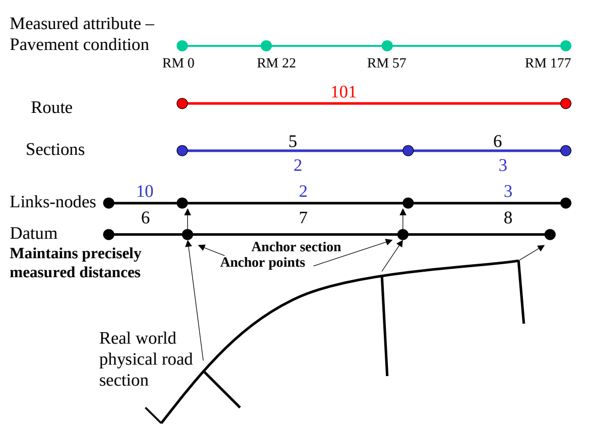
Dynamic segmentation example

Assume a set of pavement condition events referenced using the LRM Route - mile-point



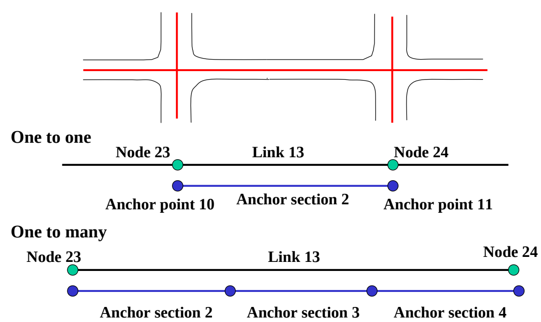
Pav cond event#	Route ID	Start Marker	End Marker	Pavement cond
10	101	RM0	RM22	Fair
11	101	RM22	RM57	Poor
12	101	RM57	RM177	Good

How do we place these events on the network?



Maintaining relations

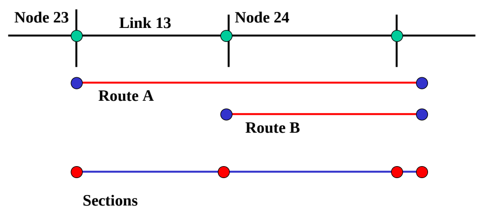
Datum to Network



Maintaining relations

Network to LRM components

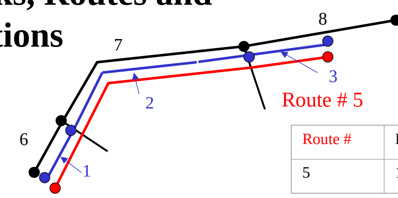
Many to many



Route: represents whole or partial links in a network, can be continuous, have branches, gaps and repeat on certain links

Sections are used to keep track of network links associated with a route

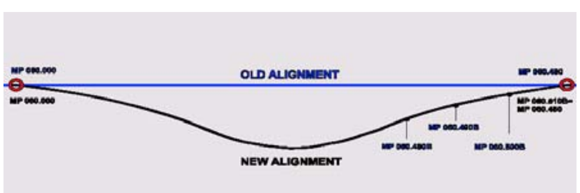
Links, Routes and Sections



Route #	Route ID
5	101

Sect ID	Link ID	From Measure	To Measure	From Pos	To Pos	Route #
1	6	0	22	0	100	5
2	7	22	108	0	100	5
3	8	108	177	0	50	5

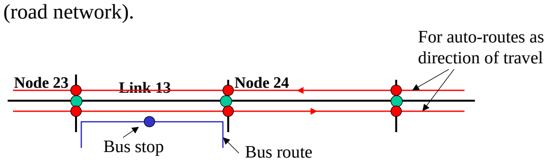
Network Update Issues



Dynamic Segmentation for Multi-modal Routing

Virtual network database design based on route systems that capture functional dependencies in multi-modal networks

Multiple systems may rely on the same underlying network (road network).



Attributes maintained as routes systems and events connected to the topological network.

ITS Data Models

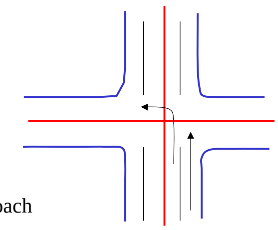
Improve use of existing capacity of systems

Suite of roadway sensor devices contribute to dynamic model of the network system and its load

Goal is to provide real time information to travelers, to traffic control devices, variable message signs

Adding complex lane and turn configurations to the data model

Need model to represent multiple lanes, lane change constraints, lane splits and merges, temporary lane modifications, lane-lane turns at intersections

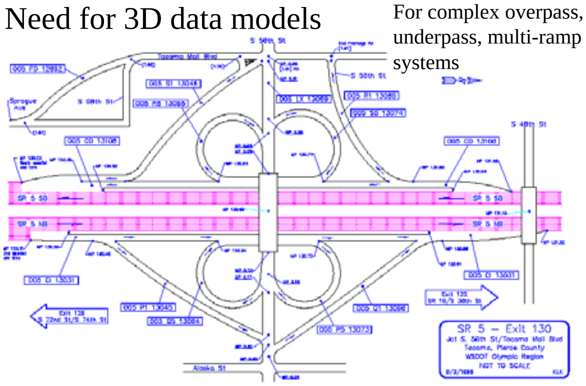


Dynamic segmentation approach assigns route to each lane

Alternative is to treat lanes as explicit objects with unique identifiers

Need for 3D data models

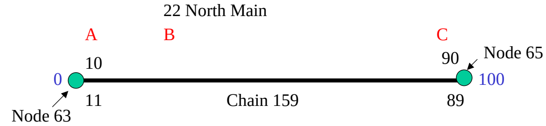
For complex overpass, underpass, multi-ramp systems



Treatment of network as ribbons that have elevation and can split and merge

Address Geocoding

22 North Main



Chain ID	From Node	To Node	From LADD	To LADD	From RADD	To RADD
159	63	65	10	90	11	89

AB/AC

12/80 = .15

100 * .15 = 15