

Network Analysis

Using Geographic Information Systems (GIS)

Shortest Path · Service Areas · Location-Allocation · Closest Facility

GIS Analysis Course | Presented by Two Students

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"Network Analysis in GIS models the movement of people, goods, and resources across connected systems — roads, pipes, power lines, and rivers."

What is Network Analysis?

- Mathematical modeling of connected geographic features
- Analysis of flow, routing, and connectivity
- Solves real-world logistics and planning problems
- Combines graph theory with spatial data

Core Applications



Transportation routing & navigation



Emergency service area planning



Utility network management



Logistics & supply chain optimization

Industries: Transportation · Emergency Services · Telecommunications · Urban Planning · Utilities

Key Concepts & Terminology

Person 1

Node

Junction point where edges meet — intersections, stops, or endpoints in the network

Edge

Linear feature connecting nodes — roads, pipes, rivers with associated attributes

Impedance

Cost of traversing an edge — time, distance, toll, speed limit

Turn Restriction

Rules limiting movement — no U-turns, one-way streets, prohibited turns

Connectivity

How edges and nodes link together — defines traversable paths

Network Dataset

GIS data structure storing all edges, nodes, and travel attributes

Types of Networks in GIS

Person 1

Transportation Network

- Roads, highways, railways
- Turn restrictions & signals
- Speed limits & travel time
- Used in routing & navigation

Utility Network

- Water, gas, electricity grids
- Flow direction & capacity
- Valve & switch locations
- Fault isolation analysis

Hydrological Network

- Rivers, canals, drainage
- Flow direction from DEM
- Catchment connectivity
- Flood routing models

Pedestrian Network

- Sidewalks, paths, stairs
- Accessibility constraints
- Barrier & crossing data
- Walkability analysis

Building a Network Dataset

1

Prepare Line Features

Clean road/pipe data — no gaps, dangles, or overlaps

2

Define Connectivity

Set endpoint/vertex connectivity rules between feature classes

3

Set Impedance

Assign travel time or distance attributes to edges

4

Add Turn Features

Import turn restriction table or digitize manually

5

Build Network

Run Build Network tool — validates topology and creates ND

6

Validate & Test

Solve a simple route to verify the network is correct

Topology Rules for Networks

Must Not Have Dangles

All edges must connect at both ends

Must Not Self-Overlap

Edges cannot cross themselves

Must Not Intersect

Edges only connect at defined nodes

Must Be Single Part

No multi-part line features allowed

Endpoints Must Touch

Lines must share exact endpoint coordinates

Shortest Path Analysis

Person 1

Dijkstra's Algorithm — How It Works

- 1 Start at origin node — set cost = 0
- 2 Assign ∞ cost to all other nodes
- 3 Visit unvisited node with lowest cost
- 4 Update neighbor costs if shorter path found
- 5 Repeat until destination node is reached

Impedance Options

Distance (meters/km) · Travel Time (minutes) · Cost (\$) · Custom composite impedance

Real-World Use Cases

Emergency Response

Fastest route for ambulance/fire trucks

Delivery Routing

Optimal multi-stop delivery sequences

Transit Planning

Efficient bus route design

Evacuation Routes

Safe paths during disaster events

Infrastructure

Critical road network assessment

What is a Service Area?

A region reachable from a facility within a specified impedance threshold — time, distance, or cost.

How It Works:

- Define one or more facility locations
- Set impedance cutoffs (e.g. 5, 10, 15 min)
- Solve generates concentric polygons
- Merge or exclude overlap between facilities
- Export to identify underserved zones

Service Area Applications

Hospitals	5, 10, 15-min drive time coverage
Fire Stations	4-minute response standard
Schools	Walking distance catchment zones
Retail Stores	Customer trade area analysis
Cell Towers	Signal coverage by terrain

Tip: Use 'Detailed Polygons' for accurate urban service areas and 'Generalized Polygons' for regional-scale visualization.

Closest Facility Analysis

Person 2

Finds the nearest facility (or facilities) to each incident location based on network impedance — not straight-line distance.

Key Inputs

Facilities	Hospitals, fire stations, stores, schools
Incidents	Emergency calls, customer locations, events
Impedance	Travel time or distance limit
Cutoff	Max acceptable travel (e.g. 20 min)
# to Find	Return closest 1, 2, or N facilities

Real-World Scenarios

- Which hospital is closest to each accident scene?
- Nearest available police unit to an incident
- Closest defibrillator to a cardiac event
- Nearest repair crew to a broken utility
- Nearest shelter during a disaster event

Direction: Can solve FROM incidents TO facilities OR from facilities TO incidents — critical for dispatch routing.

Determines OPTIMAL facility locations to serve a set of demand points – minimizing cost, distance, or maximizing coverage.

Problem Types

Minimize Impedance

Minimize total weighted travel – best for warehouses & distribution

Maximize Coverage

Cover max demand within cutoff – best for emergency services

Minimize Facilities

Fewest facilities needed for full coverage – cost optimization

Maximize Attendance

Maximize demand served – retail, schools, clinics

Example: A city needs to place 5 new clinics to serve 200 neighborhoods – Location-Allocation finds the 5 optimal sites that minimize average travel time for all residents.

Building a Network Dataset in GIS

Person 2

Step-by-Step Workflow (ArcGIS Pro / QGIS)



ArcGIS Pro Approach

- Use 'Create Network Dataset' wizard
- Import OSM or local road shapefile
- Set Minutes & Kilometers fields
- Define turn feature class
- Build & verify with Network Analyst toolbar

QGIS / Open-Source Approach

- Download OSM data via QuickOSM plugin
- Use GRASS GIS v.net for network prep
- pgRouting (PostgreSQL) for advanced routing
- QNEAT3 plugin for network analysis
- Validate with topology checker

Data Source: OpenStreetMap (free) · National road datasets · HERE / TomTom (commercial) · Local municipality GIS

Urban Transportation

- Traffic signal optimization
- Public transit route design
- Pedestrian accessibility mapping
- Congestion bottleneck detection

Emergency Services

- Fire station coverage analysis
- Ambulance dispatch routing
- Police patrol zone design
- Disaster evacuation planning

Retail & Logistics

- Store site selection
- Delivery fleet routing
- Last-mile optimization
- Warehouse location planning

Public Health

- Hospital catchment areas
- Vaccine distribution routing
- Healthcare access equity
- Disease spread modeling

Case Study: Emergency Service Optimization

Person 2

Study Area: Riyadh City Road Network | Network: 42,000 road segments | Goal: Optimize 8 fire station locations

Problem Setup

- Population demand: 7.5M residents
- Existing stations: 8 locations
- Network dataset: OSM + municipality
- Impedance: drive time (minutes)
- Target: 4-min response standard

Analysis Results

- Current coverage: 61% within 4 min
- Optimized coverage: 89% (+28%)
- 3 stations relocated, 2 added
- Average response time: -2.1 min
- High-risk zones fully covered

Recommendations

- Relocate Station #3 to Al-Malaz
- New station needed in East Riyadh
- Priority: industrial zone coverage
- Dynamic routing during peak hours
- Annual review of demand patterns

Impact: Optimized network reduced estimated response time for 850,000 additional residents – potentially saving 120+ lives annually.

ArcGIS Pro Network Analyst

Full NA toolset: Route, Service Area, Closest Facility, Location-Allocation

QGIS + QNEAT3

Open-source network analysis with OSM integration

pgRouting

PostgreSQL extension for scalable routing algorithms

OpenRouteService

Open API for routing, isochrones, matrix calculations

NetworkX (Python)

Graph analysis library for custom network algorithms

HERE / Google Maps

Commercial APIs for real-time traffic-aware routing

Conclusion

GIS Network Analysis transforms raw geographic data into powerful decision-support tools. From finding the shortest route to optimizing entire emergency service networks, it enables planners, engineers, and policymakers to make evidence-based spatial decisions. As cities grow more complex, network analysis remains one of the most impactful capabilities in the GIS toolkit.