Vulnerability Assessment of Alberta’s Highway Network Under Extreme Events

Kasturi Mahajan

Graduate Research Assistant

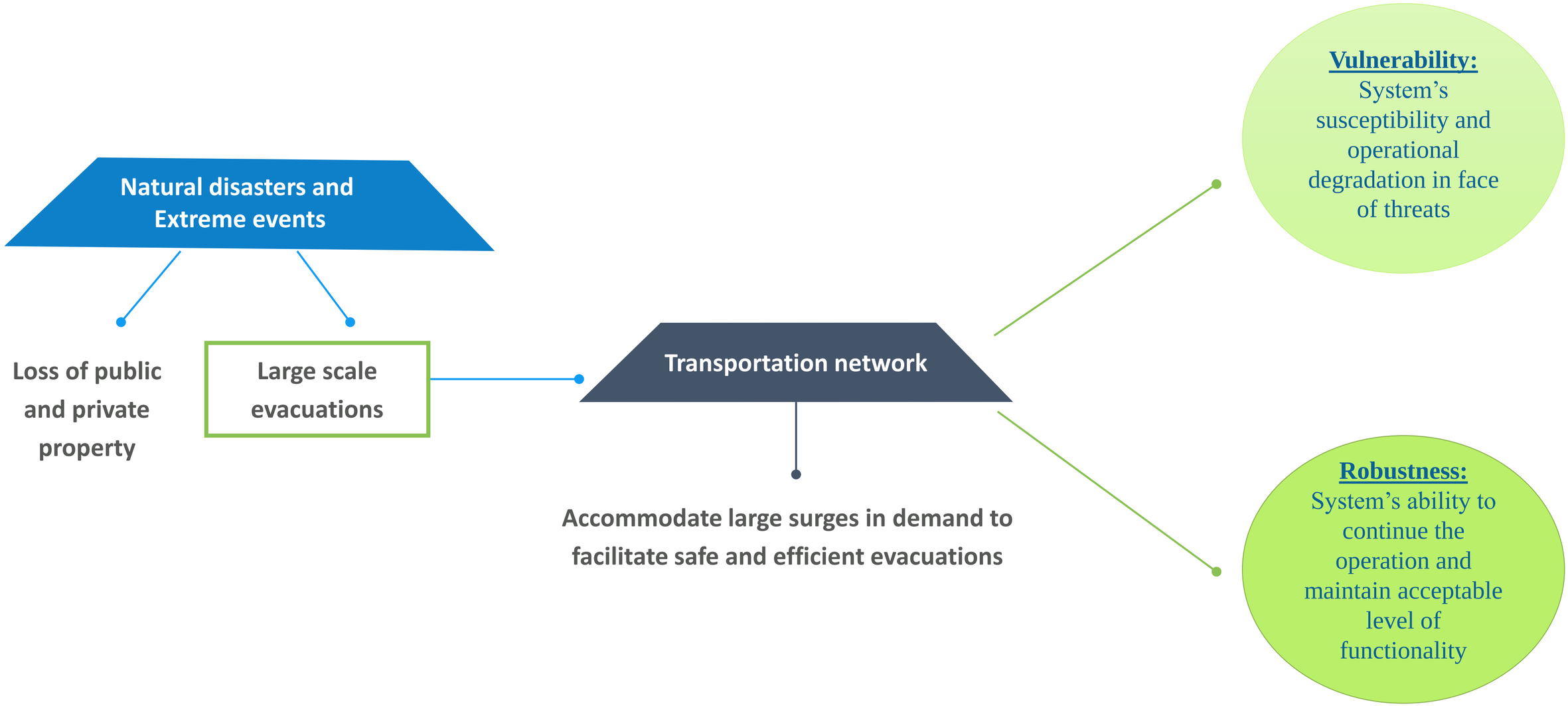
Univeristy of Alberta

Dr. Amy Kim

Associate Professor

Univeristy of Alberta

NATURAL DISASTERS AND TRANSPORTATION NETWORK



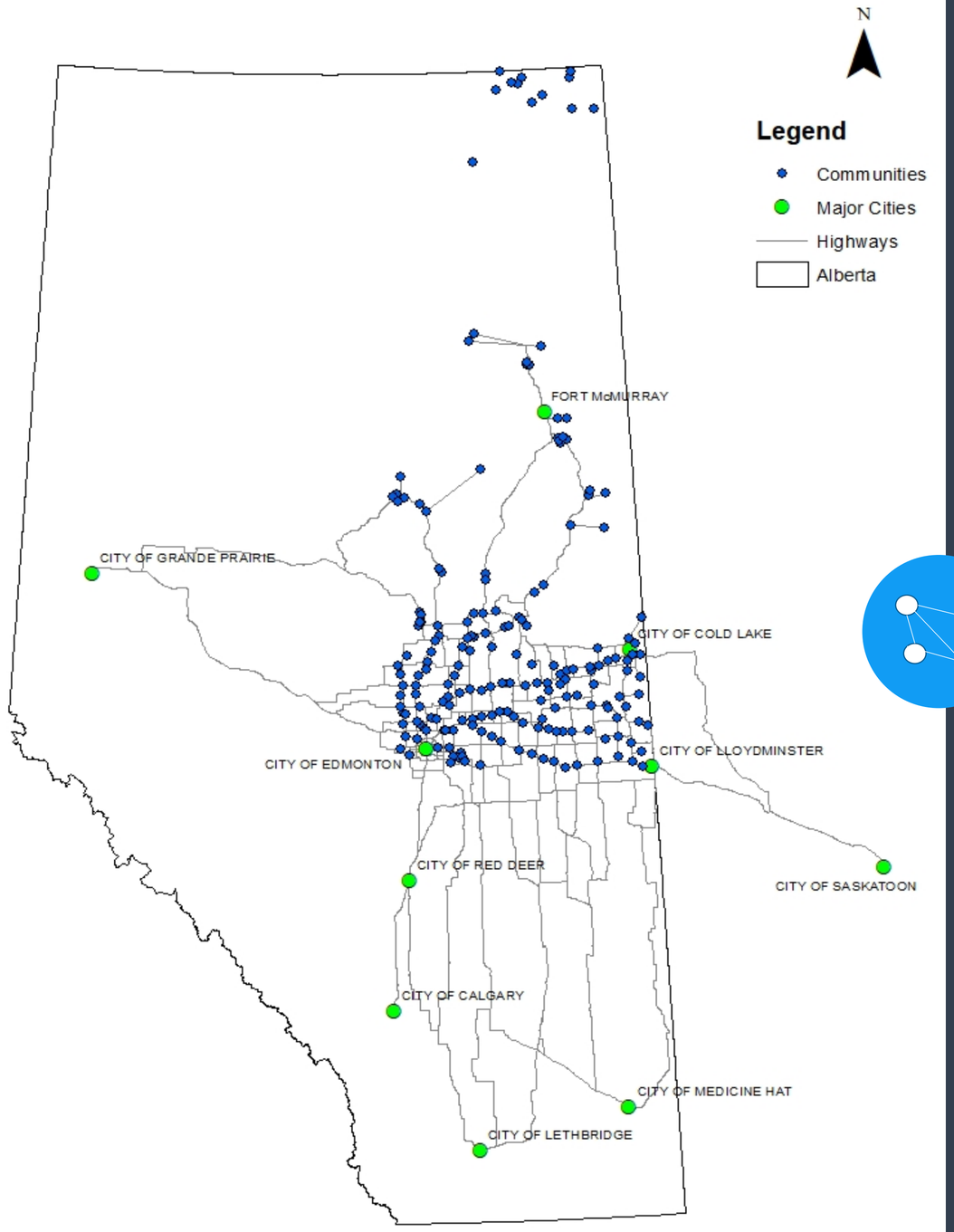
OBJECTIVE AND PROCESS

OBJECTIVE

- Understand interconnectedness of Alberta's highway system and identify communities at risk in an emergency situation
- Explore how network topology puts communities and highways at risk in case of emergencies

PROCEDURE

- Network representation using node-link system
- Employed topological metrics to measure network performance
    - Topological measures: measures that use nodes, links and the node-link arrangement to characterize the transportation network → focuses on Vulnerability of transportation network
    - Network performance was measured in terms of difficulty to vacate a community and access basic services during emergency



NETWORK REPRESENTATION

STUDY REGION

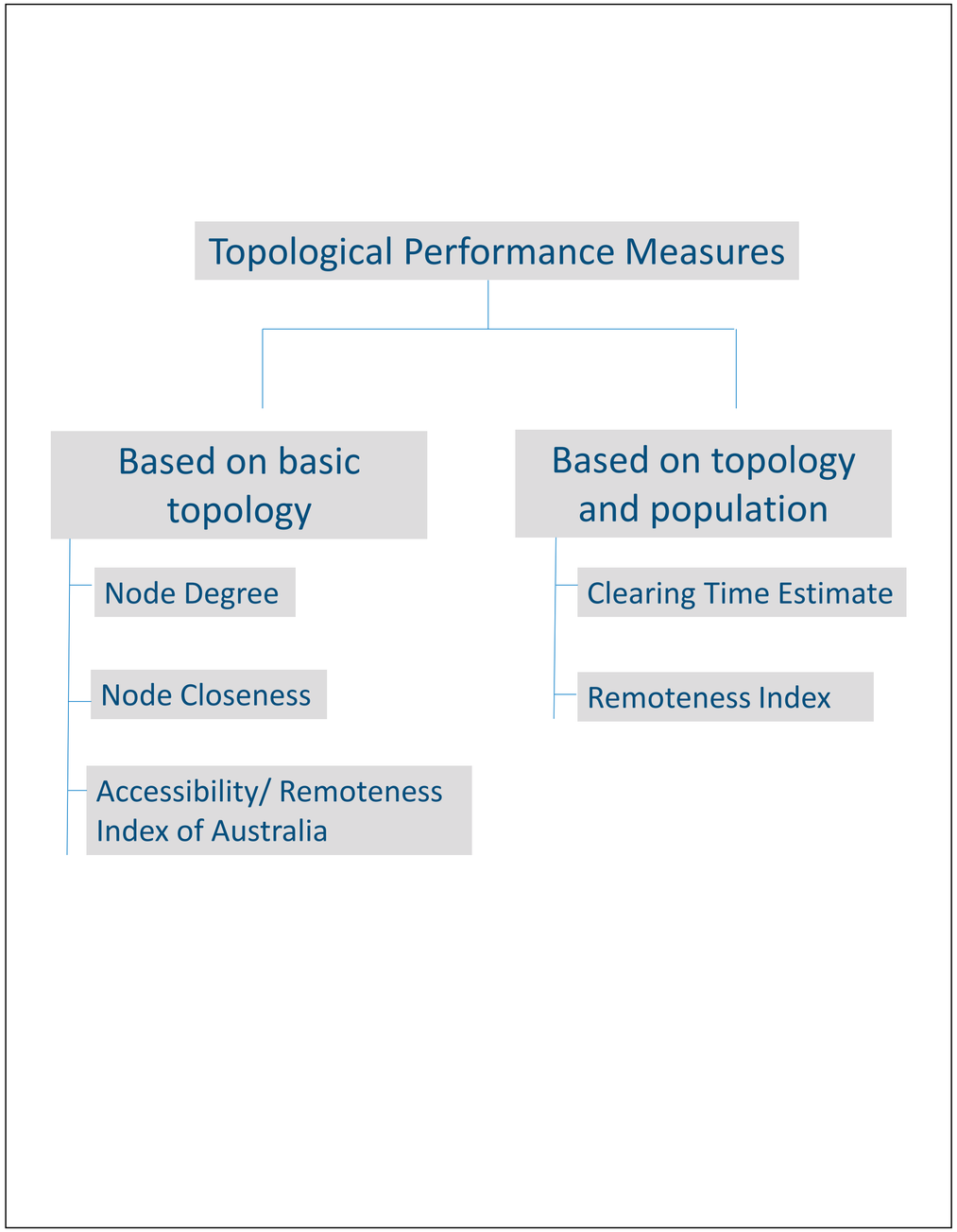
- Communities in north eastern quadrant of Alberta connected to major cities in the province
- Specifically, communities towards the north and east of Edmonton
- Focus on the sparse network

COMMUNITIES

- Represented as nodes
- Communities include: hamlets, villages, cities, towns and First Nations

HIGHWAY NETWORK

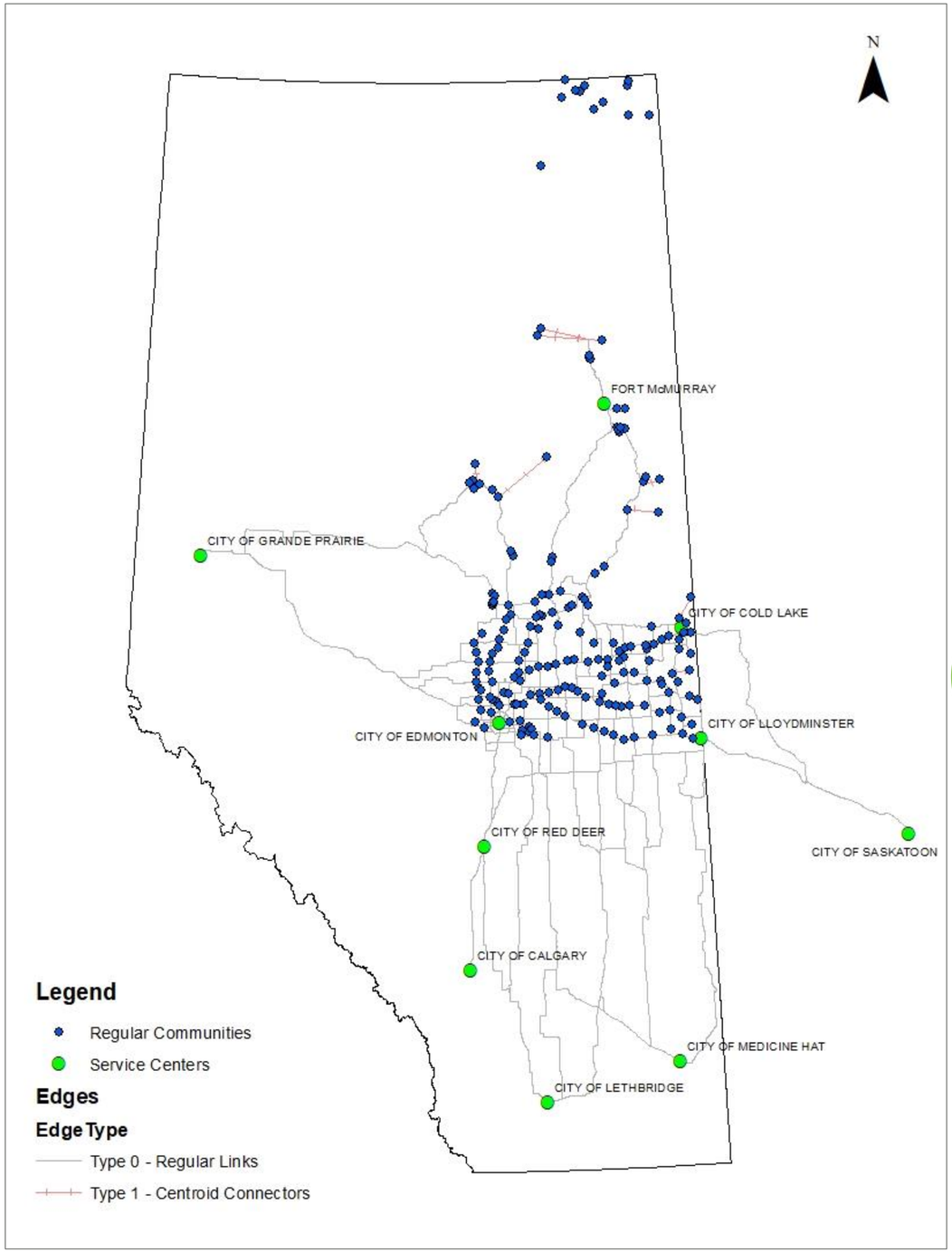
- Represented as links
- Only provincial highway system



PM's

PERFORMANCE MEASURES

- **TOPOLOGICAL MEASURES** **VULNERABILITY MEASURES**
  - Metrics used to measure the impact of disruption on transportation network
  - Based on network topology: node-link arrangement and path lengths
  - A undirected graph of the network is made and paths are calculated based on adjacency matrix



SHORTEST PATH ANALYSIS

NETWORK GRAPH

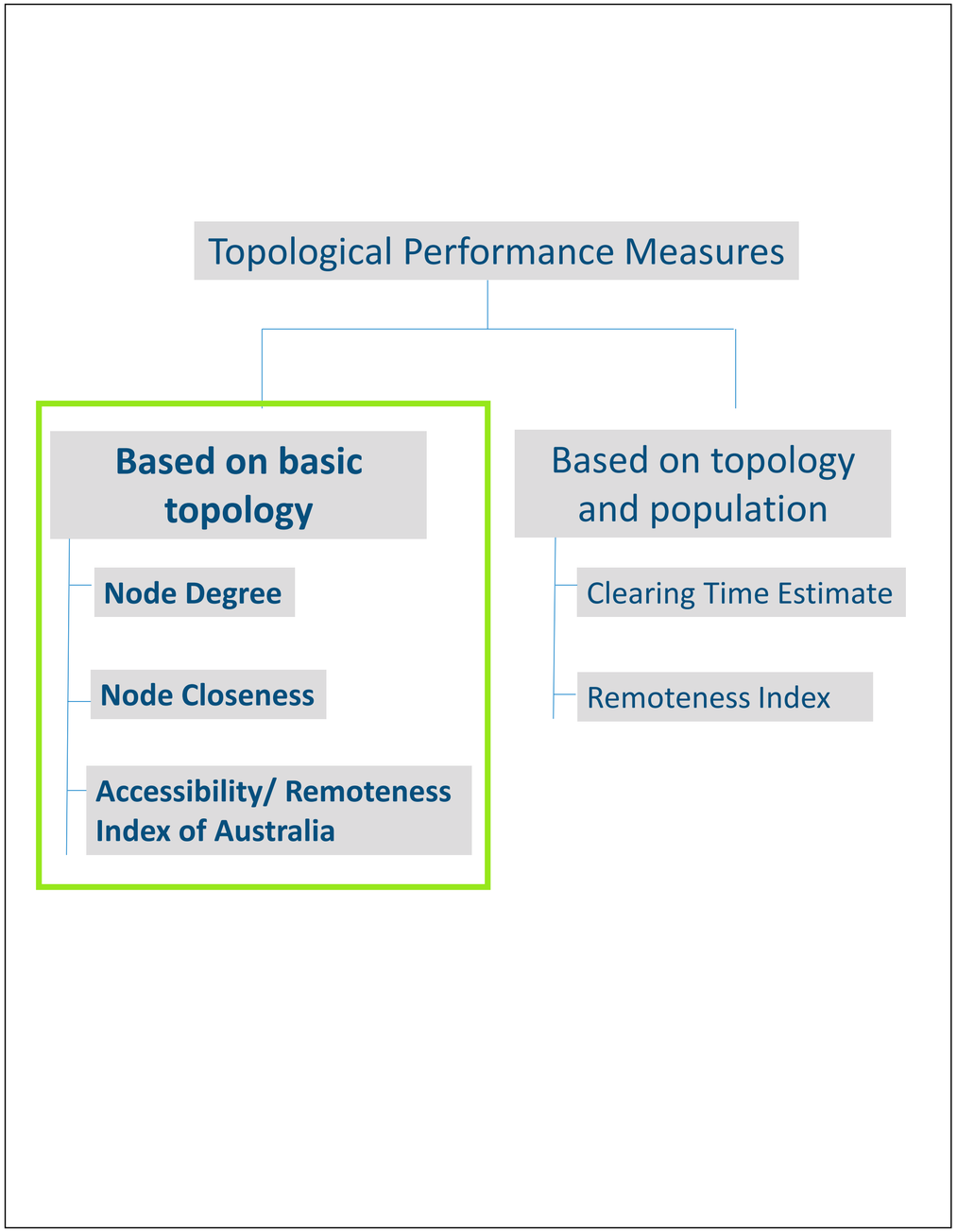
- A undirected weighted graph of the network with weights equal to distance

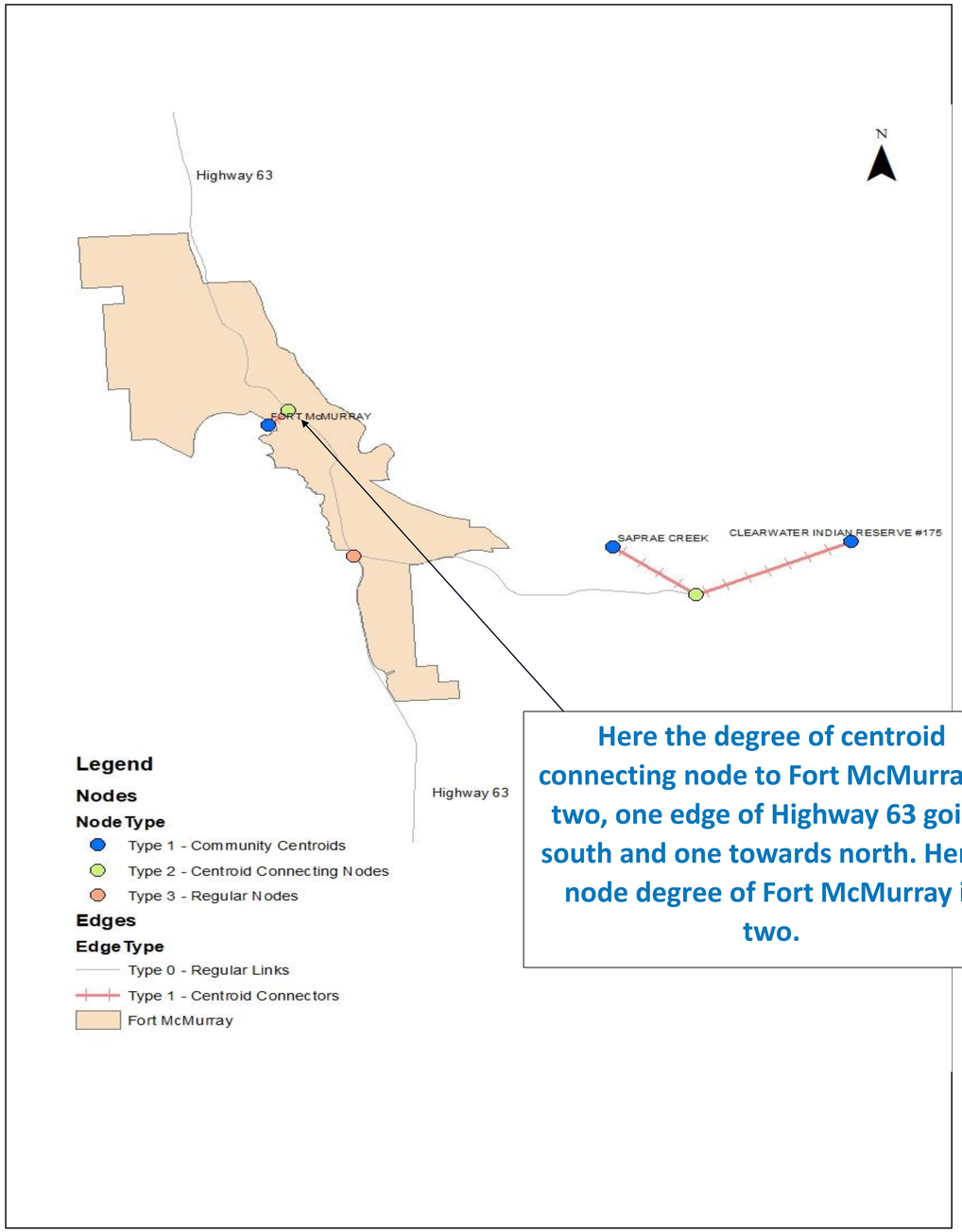
SHORTEST PATH ANALYSIS

- Shortest path analysis is based on Dijkstra's shortest path algorithm
- Shortest path is the minimum distance path between an origin-destination pair

EVACUATION SCENARIO

- Origins: Communities assumed to be at risk that evacuate to nearest service center
- Destination: Service center, a city with population>1000 that acts as provider for basic and emergency relief services.
- Communities are assumed to evacuate to service center using shortest path


Topological Performance Measures
Based on basic topology
Node Degree
Node Closeness
Accessibility/ Remoteness Index of Australia
Based on topology and population
Clearing Time Estimate
Remoteness Index



Here the degree of centroid connecting node to Fort McMurray is two, one edge of Highway 63 going south and one towards north. Hence node degree of Fort McMurray is two.

NODE DEGREE

- Node degree refers to the number of edges directly connected to a node. More specifically, number of highway links connected to a community centroid node

  The degree of a node is defined as,

$$D_i = \sum_{k=1}^{N} a_{ik}$$

D_i: *Degree of node* i

k: *any other node in the network excluding* i

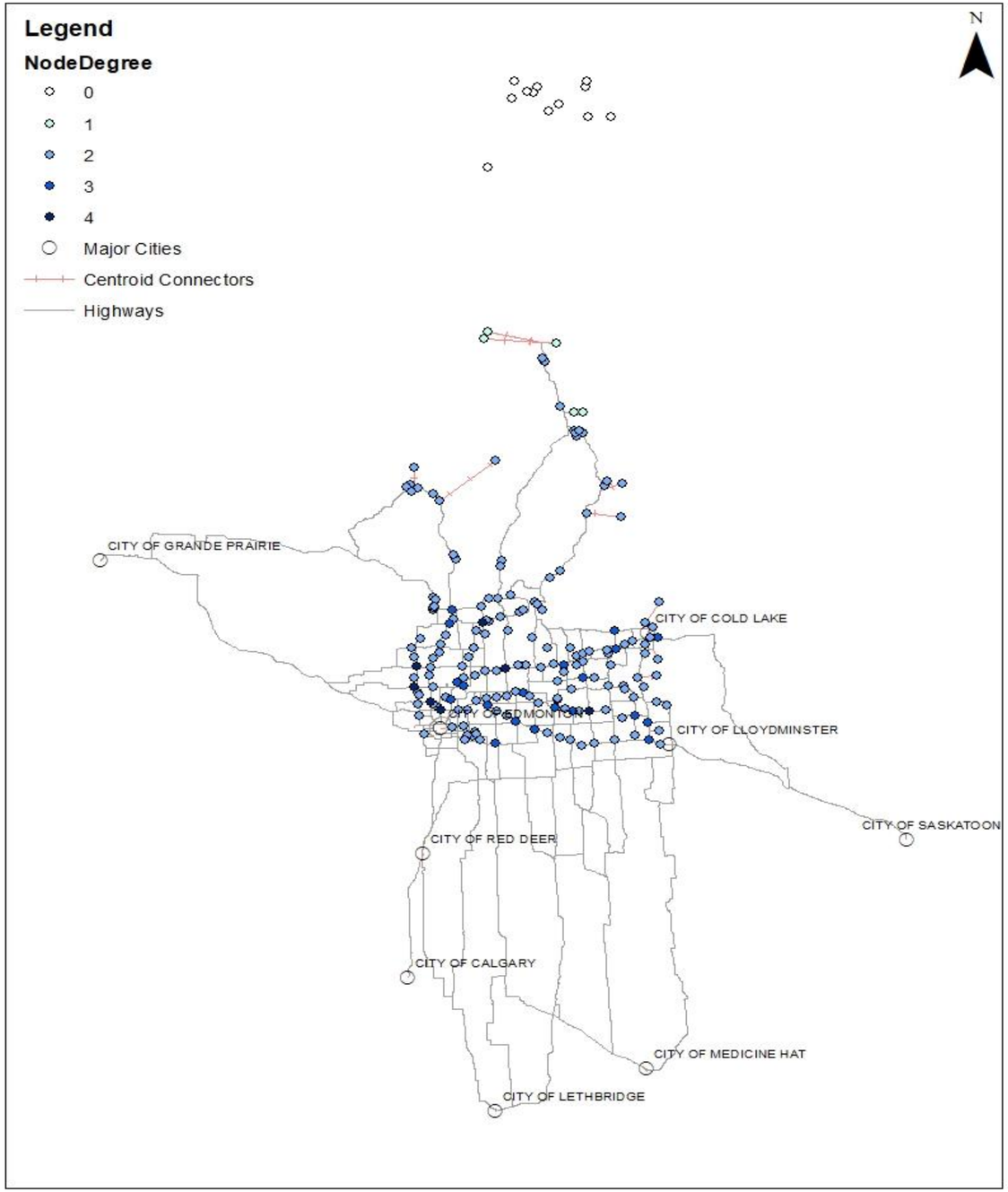
N: *total number of nodes in the network*

a_{ik}: ik *element of the node adjacency matrix* A.

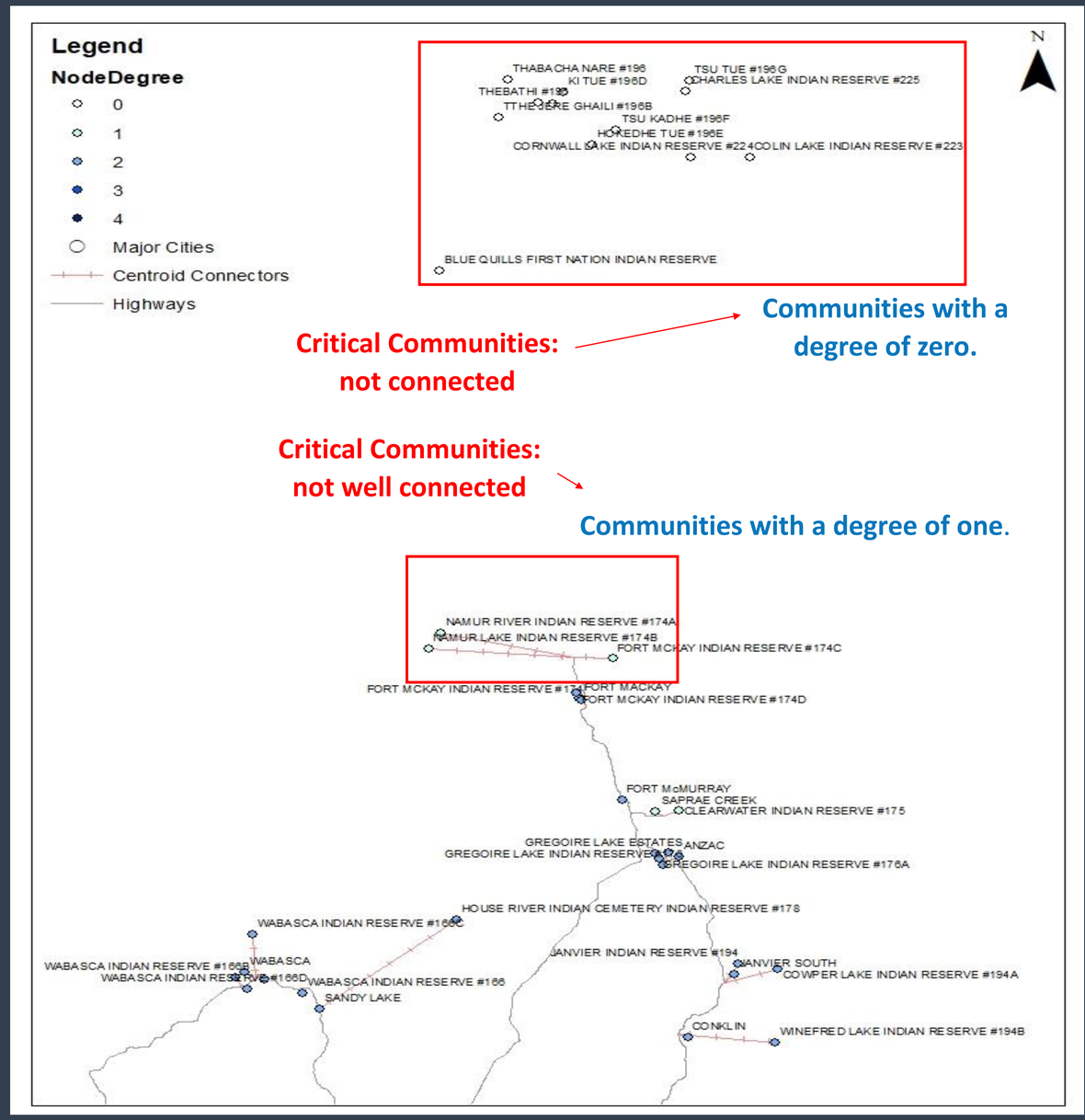
  a_{ik} takes a value of 1 if and only if nodes i and k are directly connected with a link.

- It counts the number of immediate exits available to vacate a community during an emergency

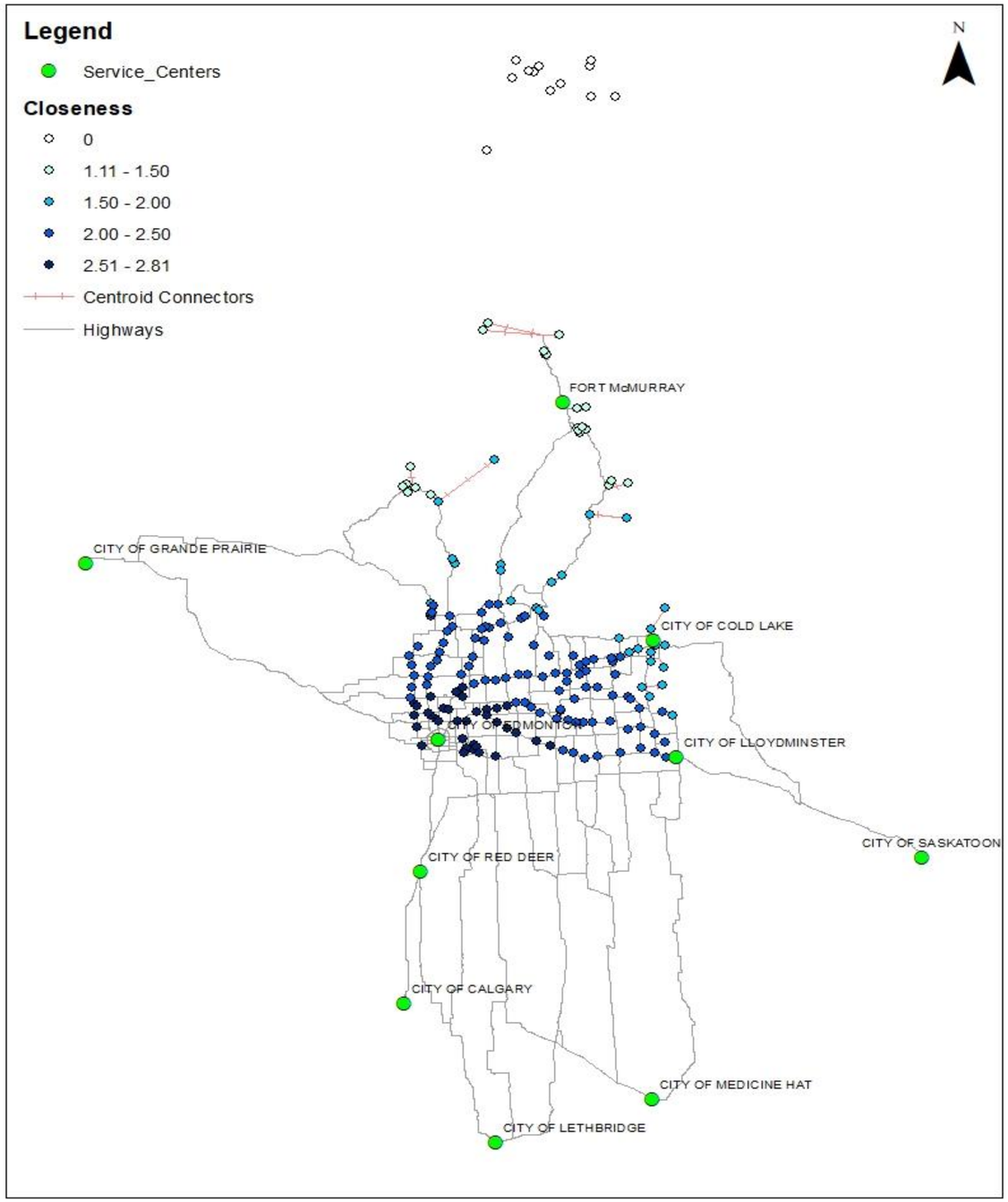
Node Degree Results



NODE DEGREE



Node Closeness Results



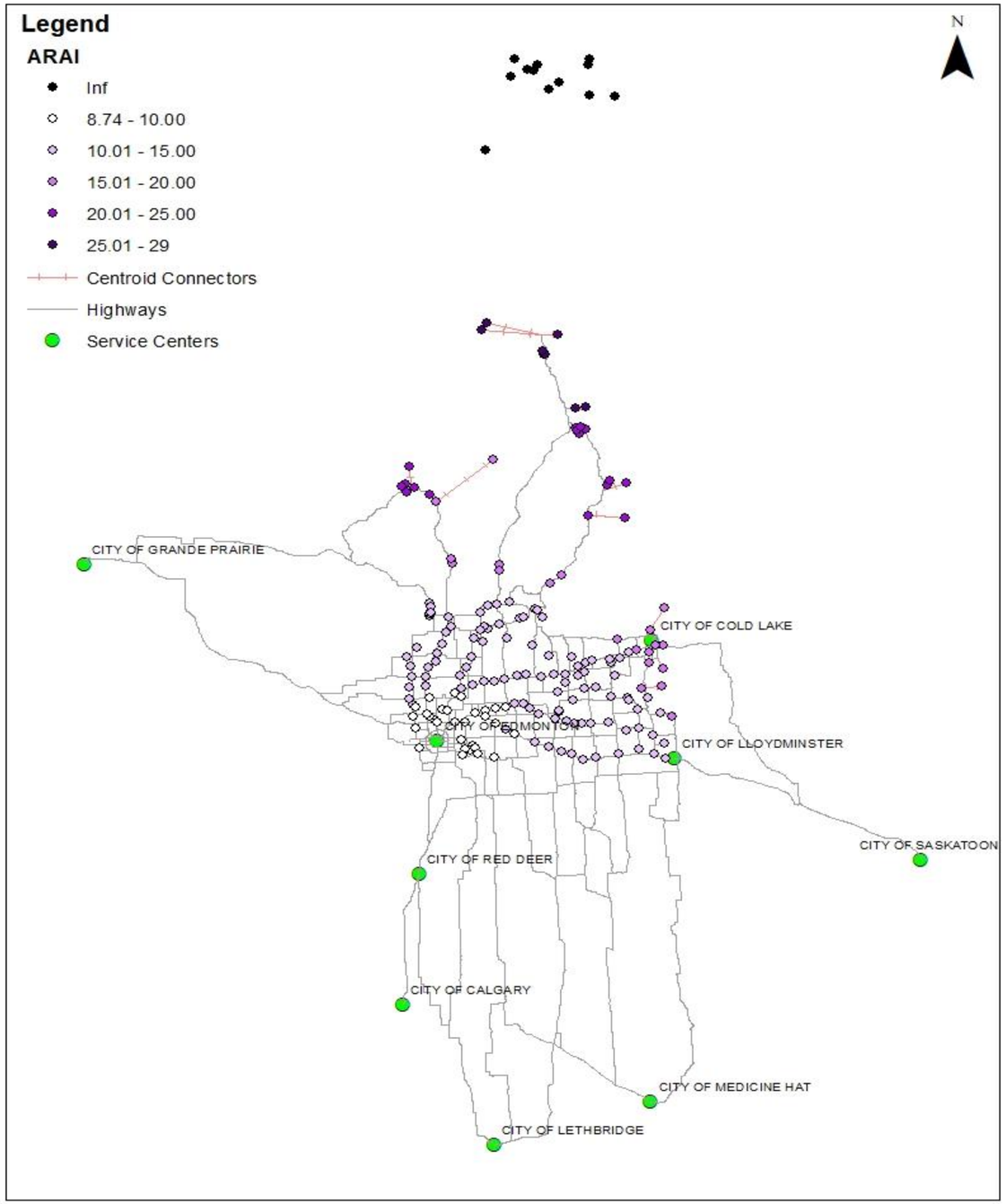
NODE CLOSENESS

- It measures how close is community 'i' to all service centers along the shortest path in the network

$$C_i = \frac{1}{\sum_{k=1}^{M} d_{ik}}$$

$$C_i = Closeness\ of\ node\ i$$
$$d_{ik} = Geodesic\ distance\ between\ nodes\ i\ and\ k$$
$$i = Community\ centroid$$
$$k = Service\ centre$$
$$M = Total\ number\ of\ service\ centers\ in\ the\ network$$

- Lower Node Closeness → more remote the community in terms of service provision
- Disconnected communities in the North have a 0 node closeness value and are the most remote
- The closeness value starts increasing as we move towards the center of the province as the major service centers are located here



ACCESSIBILITY AND REMOTENESS INDEX OF AUSTRALIA

- Accessibility/Remoteness Index of Australia (ARIA) : ratio of the road network distance from a community to the nearest service center to the average distance of all communities to that service center

$$ARIA_i = \sum_k \frac{d_{ik}}{\overline{d_{k\forall i}}}$$

Where,

$ARIA_i = Accesibility/Remoteness\ Index\ of\ node\ i$

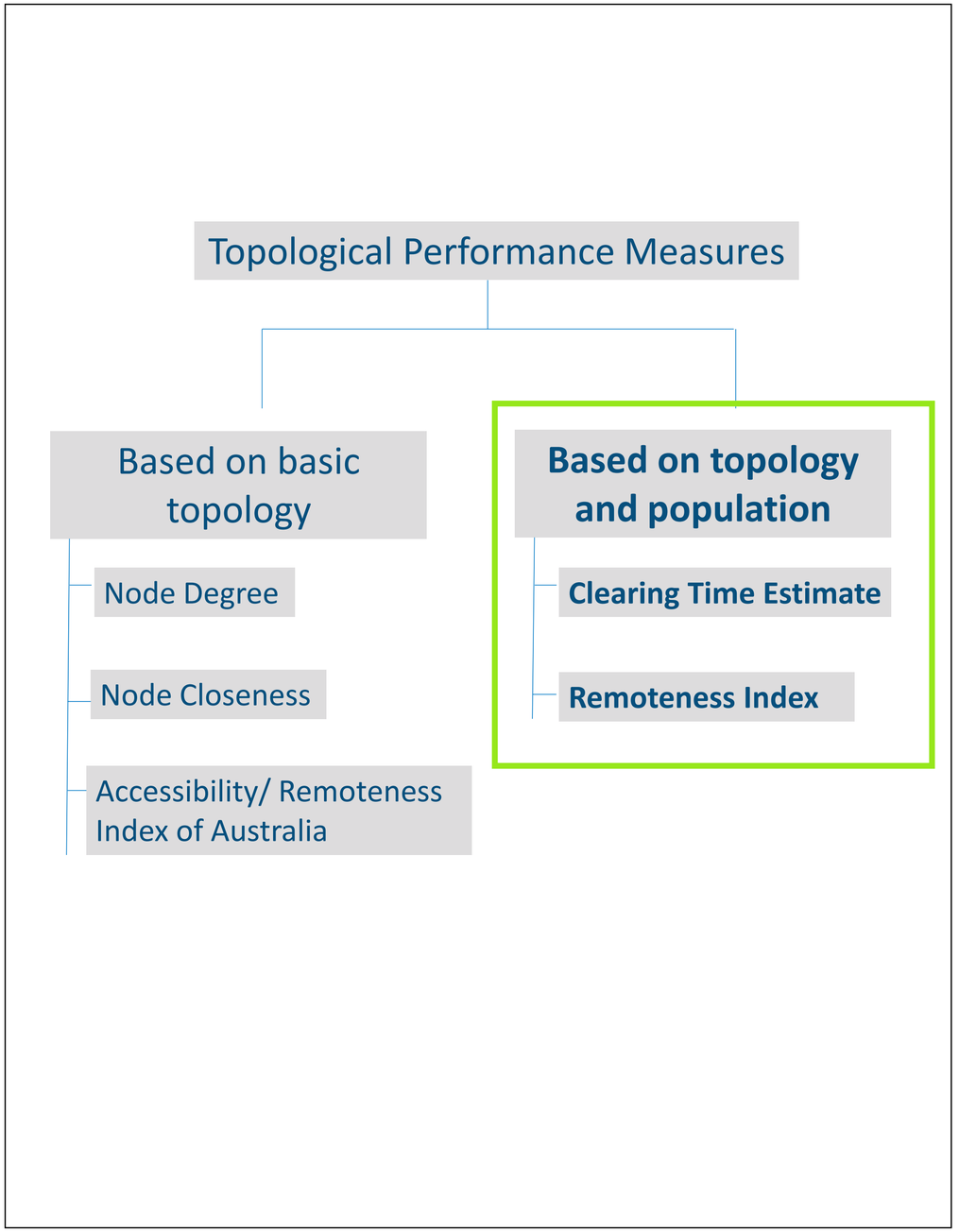
$d_{ik} = Geodesic\ distance\ between\ node\ i\ and\ k$

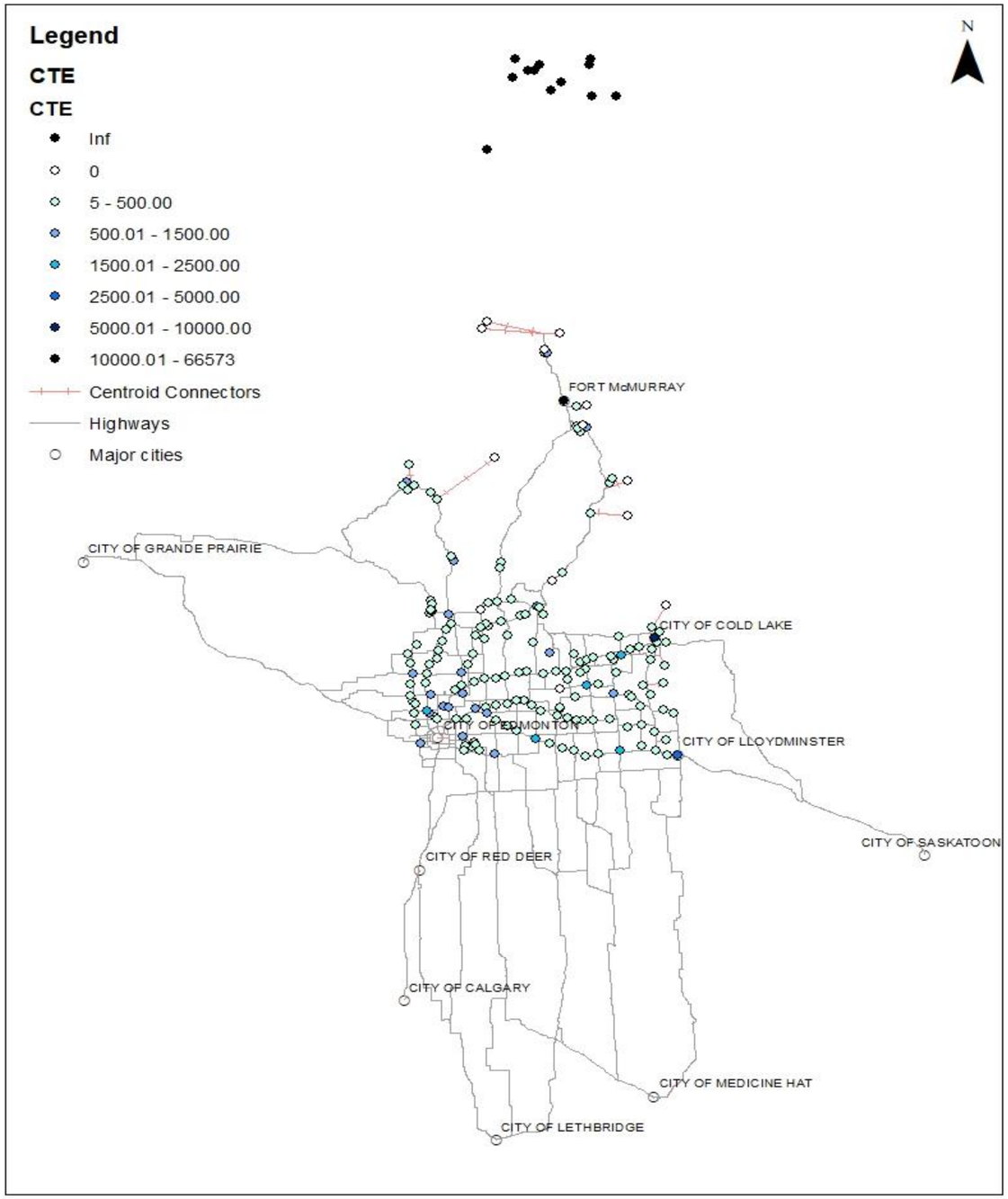
$\overline{d_{k\forall i}} = Average\ geodesic\ distance\ of\ k\ from\ all\ i's$

$i = Community\ centroid$

$k = Service\ centre$

- Higher the ARAI more remote the community
- The communities having a value of Infinity are in the extreme north and are completely disconnected
- As we move towards Edmonton the values start decreasing as the communities start becoming more accessible


Topological Performance Measures
Based on basic topology
Node Degree
Node Closeness
Accessibility/ Remoteness Index of Australia
Based on topology and population
Clearing Time Estimate
Remoteness Index



CLEARING TIME ESTIMATE

- Clearing Time Estimate is the ratio of population to the immediate number of exits out of a community
- Measure of time required to clear a neighborhood → evacuation difficulty
- The Clearing Time Estimate is defined as,

$$CTE_i = \frac{P_i}{E_i}$$

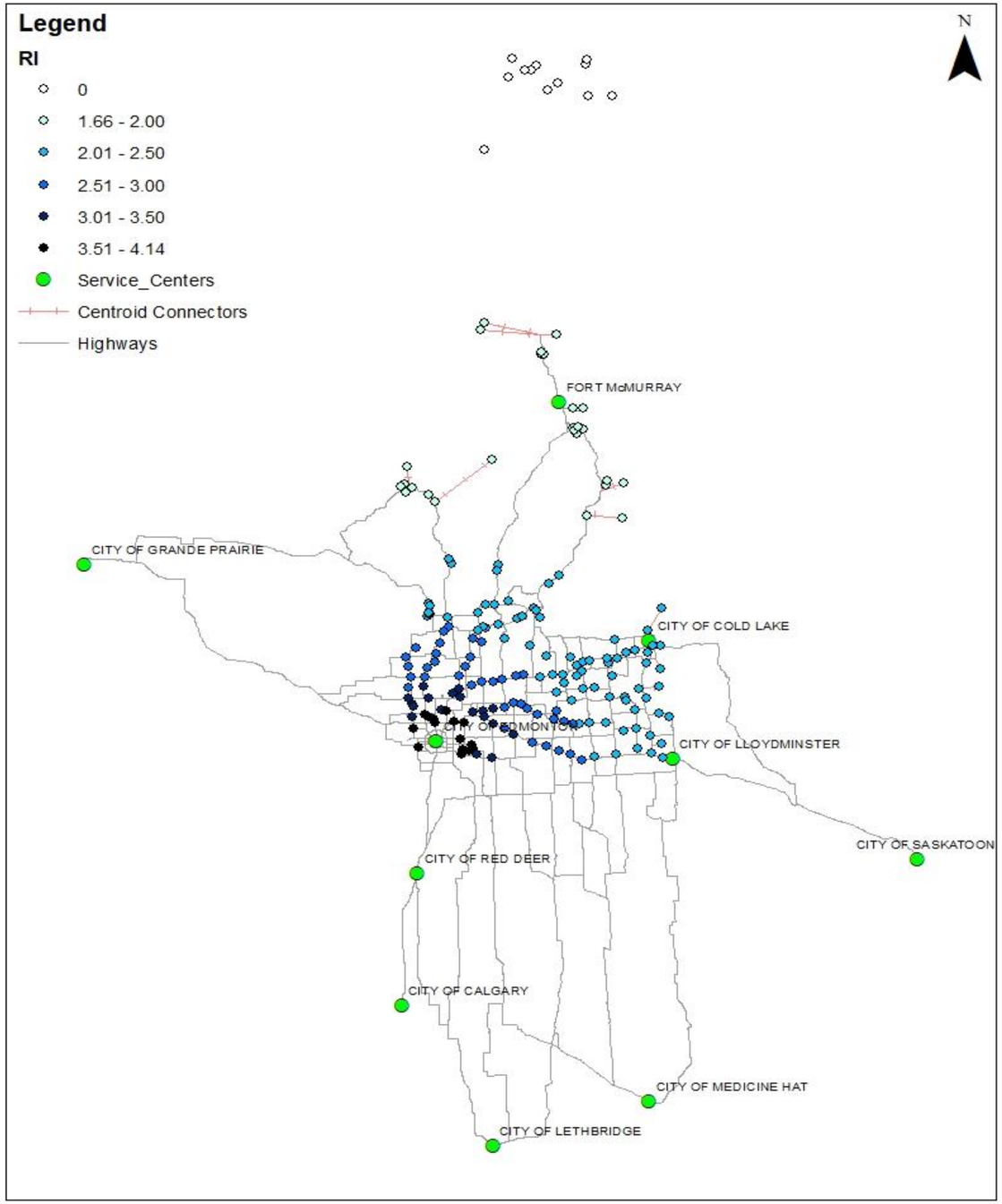
CTE_i: *Clearing Time Estimate for node i*

P_i : *population of node i*

E_i: *number of immediate exits for community i*

- Communities with high population and less number of exits have a high CTE value and are critical

Community	Population	Number of exits	CTE value
Fort McMurray	66,573	2	33,286.50
City of Cold Lake	14,961	2	7480.50



REMOTENESS INDEX

- Remoteness Index for a community 'i' is the ratio of population of service center to the shortest distance from that community to the service center summed for all the service centers

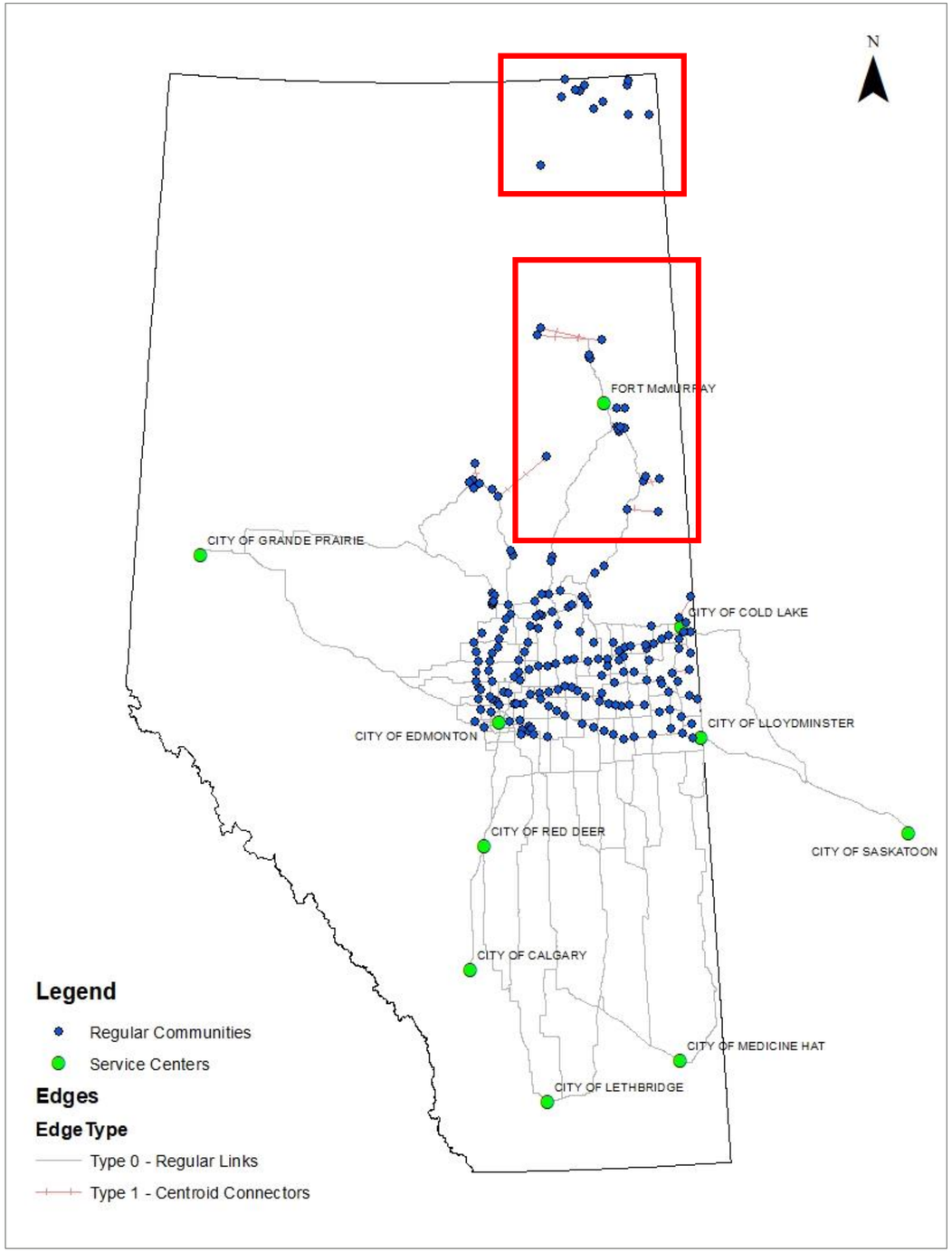
$$RI_i = ln(\sum_{k=1} \frac{P_k}{d_{ik}})$$

$$RI_i = Remoteness\ Index\ of\ node\ i$$
$$d_{ik} = Geodesic\ distance\ between\ node\ i\ and\ k$$
$$P_k = Population\ of\ node\ k$$
$$i = Community\ centroid$$
$$k = Service\ centre\ centroid$$

- Lower Remoteness Index → more remote the community from a service center
- The communities with value zero represent remote communities that are completely disconnected
- These are fly in communities and have winter road access
- The communities in Regional Municipality of Wood Buffalo have a low remoteness index as their distance from major population centers in the province is high

CONCLUSIONS

- Northernmost communities in Alberta are only accessible by winter roads and are disconnected from the highway system
- Highway network in the Regional Municipality of Wood Buffalo is sparse and the communities are remote in terms of service provision
- Fort McMurray has the highest ratio of population to exit capacity in the northeastern quadrant, and can face the most difficulty to evacuate
- Accessibility to services and connectivity for communities starts increasing towards the center of the province (along Highway 2 corridor)
- Finally, communities not connected or connected with only one provincial highway are the most critical



Images:
Title page: globalnews.ca
Current page: macleans.ca

Thank you!