Transportation Network Analysis

Circuitry

Circuitry **- difference between measured route length and geometric distance between two places.**

- **The difference between actual and straight-line distances.**
- **A measure of route efficiency, in that straighter routes are more efficient.**

Circuitry is calculated as the difference between measured route length and geometric distance divided by the measured route distance.

$$k_{ij} = \frac{(l_{ij} - d_{ij})}{l_{ij}}$$

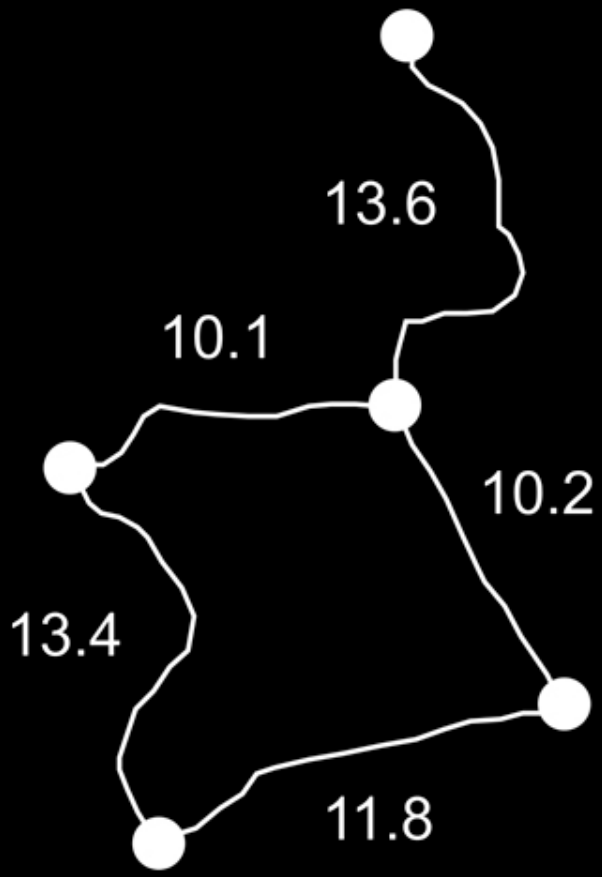
where k is the circuity of node j, l_{ij} is the route distance of the link from node i to node j, and d is the geometric distance.

Circuitry ranges from 0 to 1.

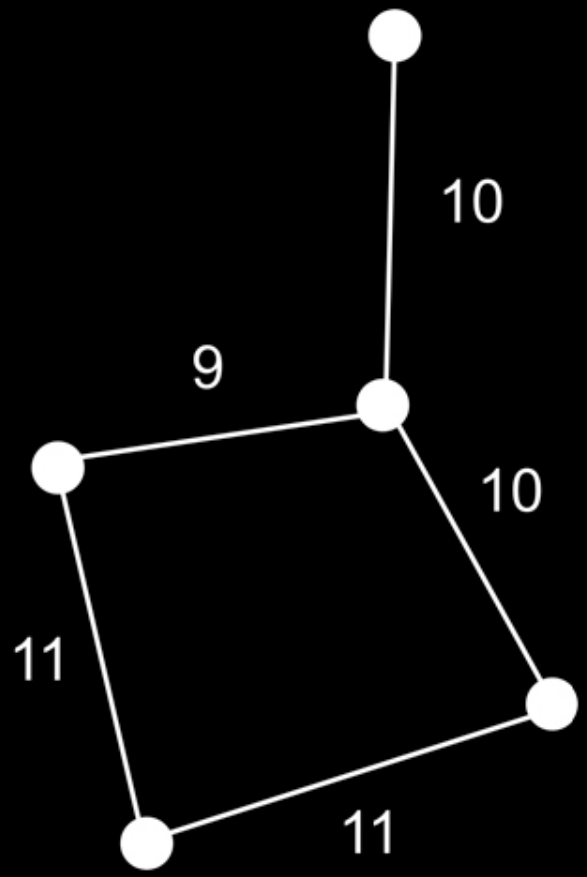
- A value of 0 means the route is non-circuitous (straight).
- A value approaching 1 means the route is very circuitous.

Values will never reach 1, since the potential difference between actual distance and geometric distance is infinite.

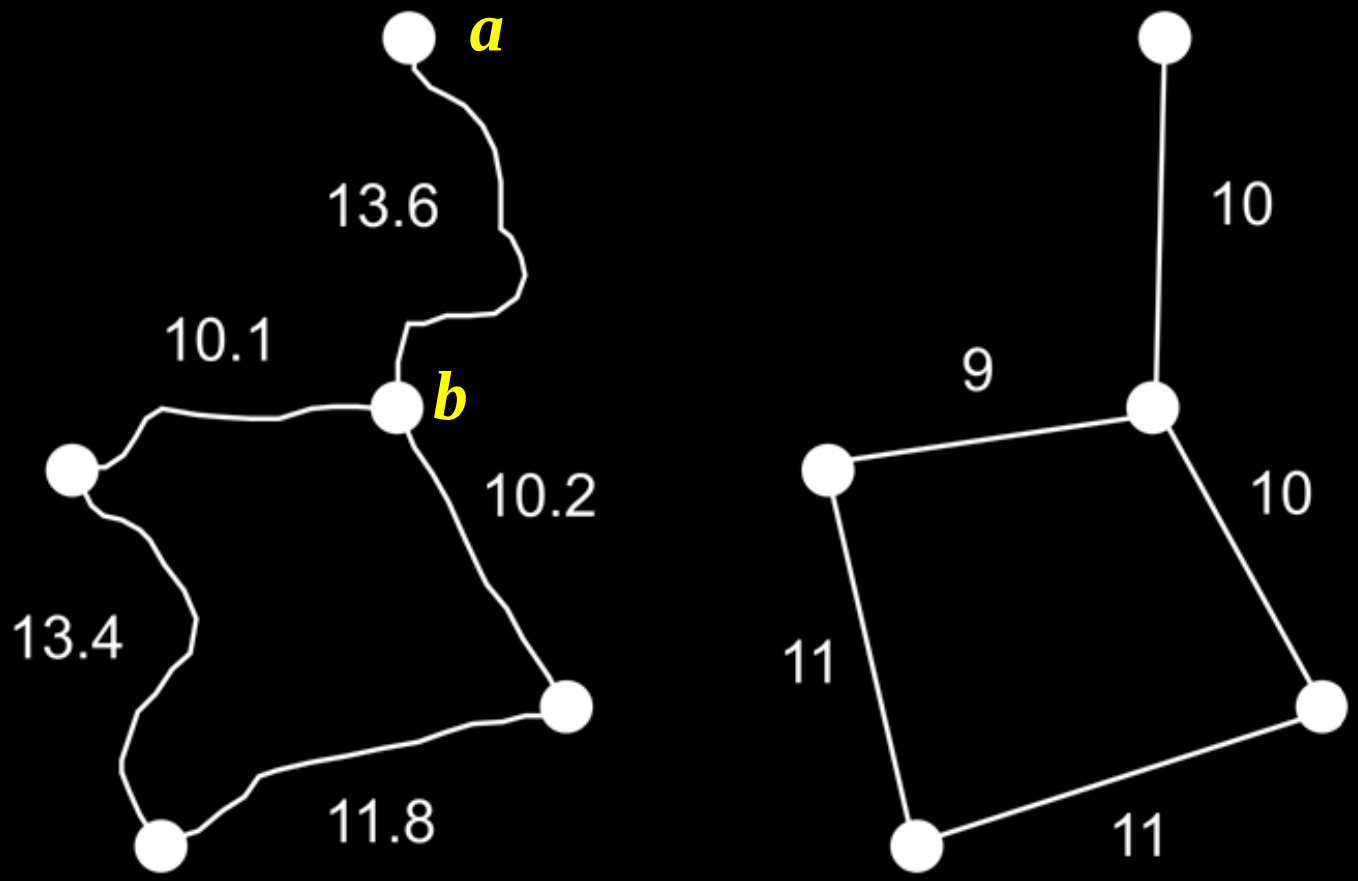
Measured Route Length



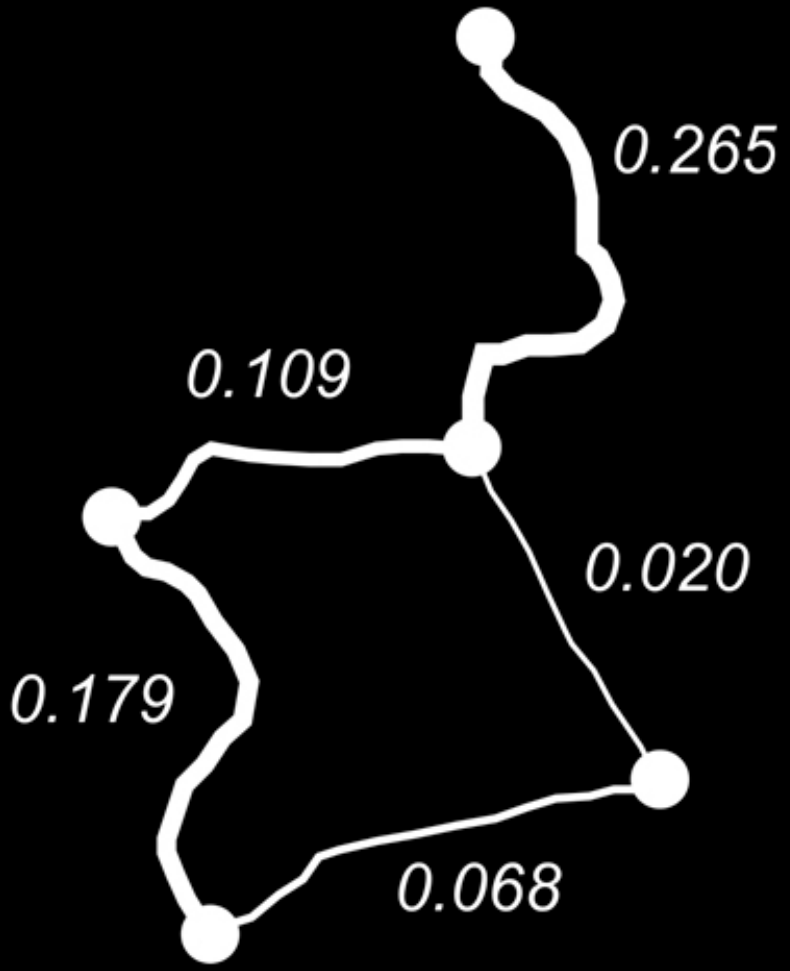
Geometric Distance



$$k_{ab} = \frac{(13.6 - 10)}{13.6} = 0.265$$



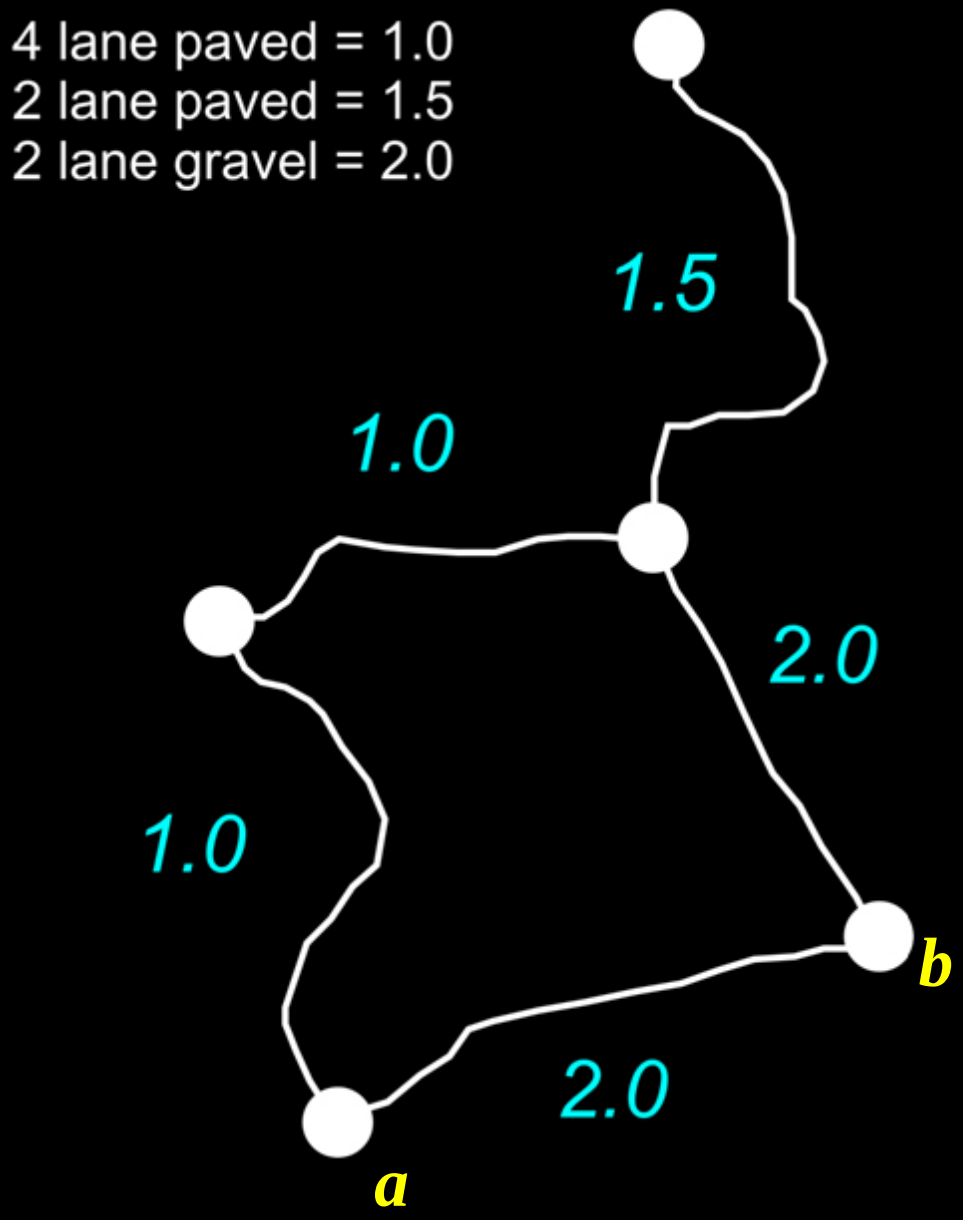
This measurement is used to describe specific routes, and each route can then be mapped based on its circuitry.



Thus far we have treated all routes as being equal.

- This is often not the case.
- There are many factors which influence routes:
    1. Presence of street lights, stop signs, etc.
    2. Number of lanes.
    3. Speed limit.

Therefore it may be preferable to *weight* the routes based on some factor measurement.


4 lane paved = 1.0
2 lane paved = 1.5
2 lane gravel = 2.0
1.5
1.0
2.0
1.0
2.0
a
b

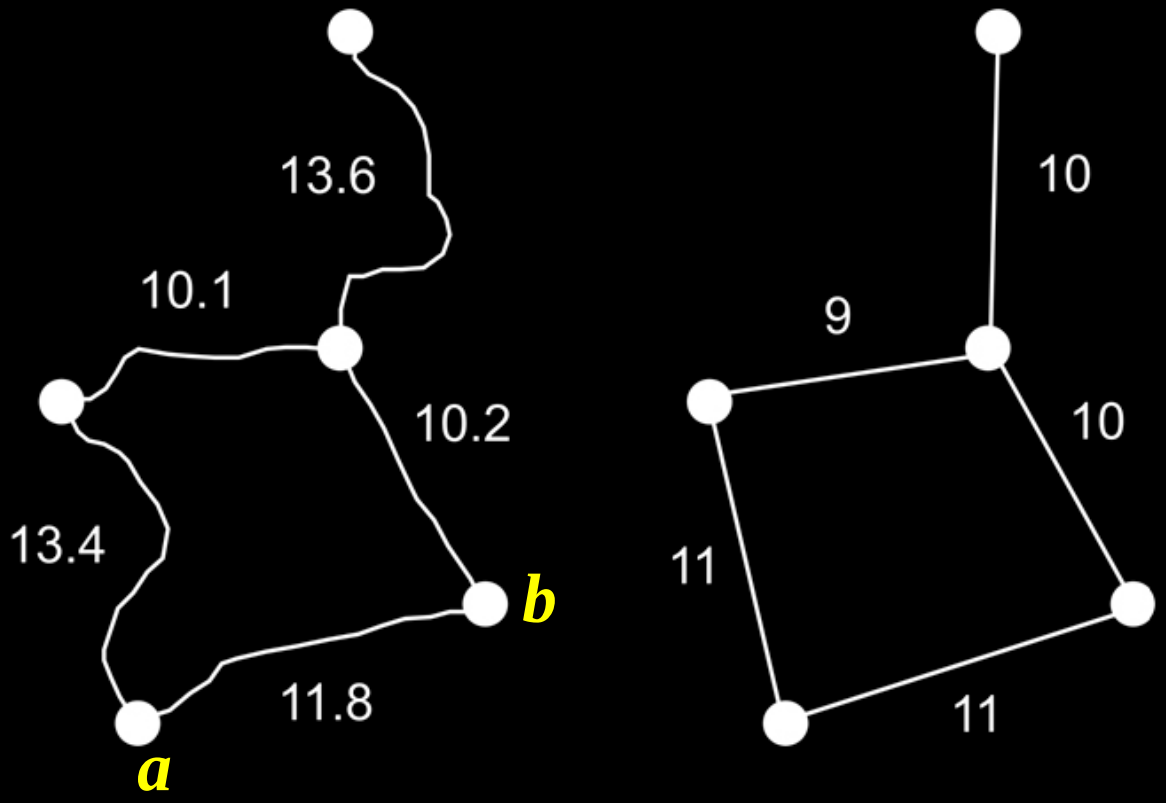
Weighted Circuitry

$$k_{ij} = \frac{((l_{ij} * w_{ij}) - d_{ij})}{l_{ij}}$$

where w_{ij} is the weighting factor.

When weights are applied the range of k is from 0 to ∞.

$$k_{ab} = \frac{((11.8 * 2) - 11)}{11.8} = 1.07$$



Unweighted

$$k_{ab} = \frac{(11.8 - 11)}{11.8} = 0.068$$

Weighted

$$k_{ab} = \frac{((11.8 * 2) - 11)}{11.8} = 1.07$$

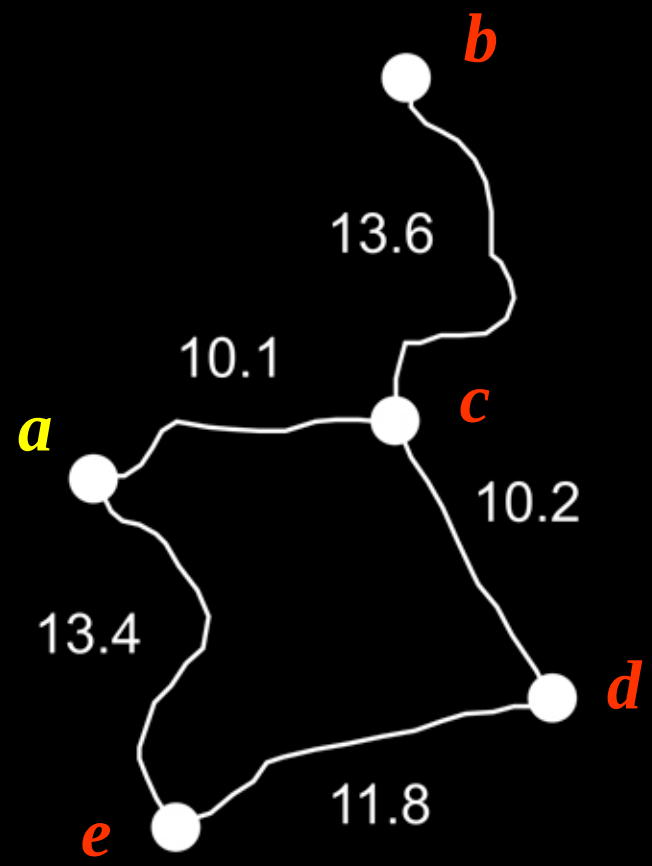
Degree of Circuitry – **a node based measurement of the actual versus geometric distance summed from one node to all other nodes *along the shortest route*.**

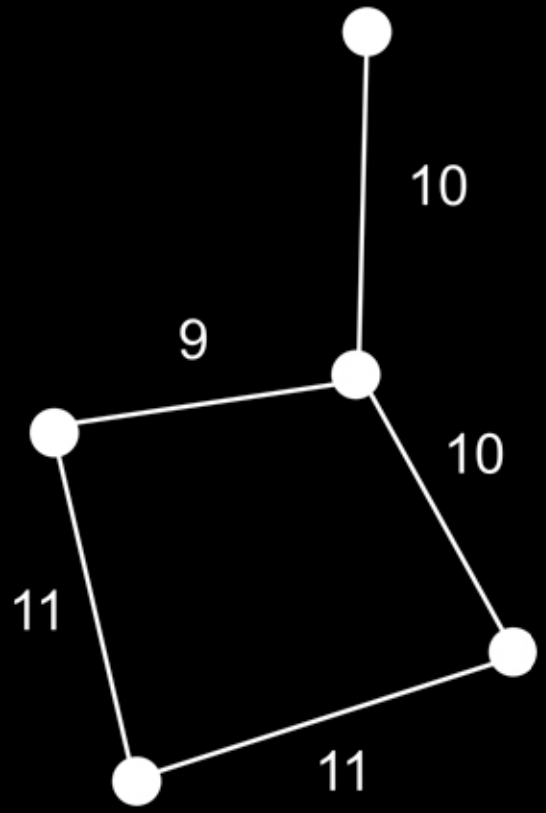
$$DC = \frac{\sum_{j=1}^{n} (E_j - d_j)^2}{n^2 - 1}$$

where *E* is the measured route length, *d* is the geometric distance of route *j*, and *n* is the number of vertices.

$$DC_a = \frac{(23.7-19)^2_{ab} + (10.1-9)^2_{ac} + (20.3-19)^2_{ad} + (13.4-11)^2_{ae}}{5^2 - 1}$$

$$DC_a = \frac{30.75}{24} = 1.28$$





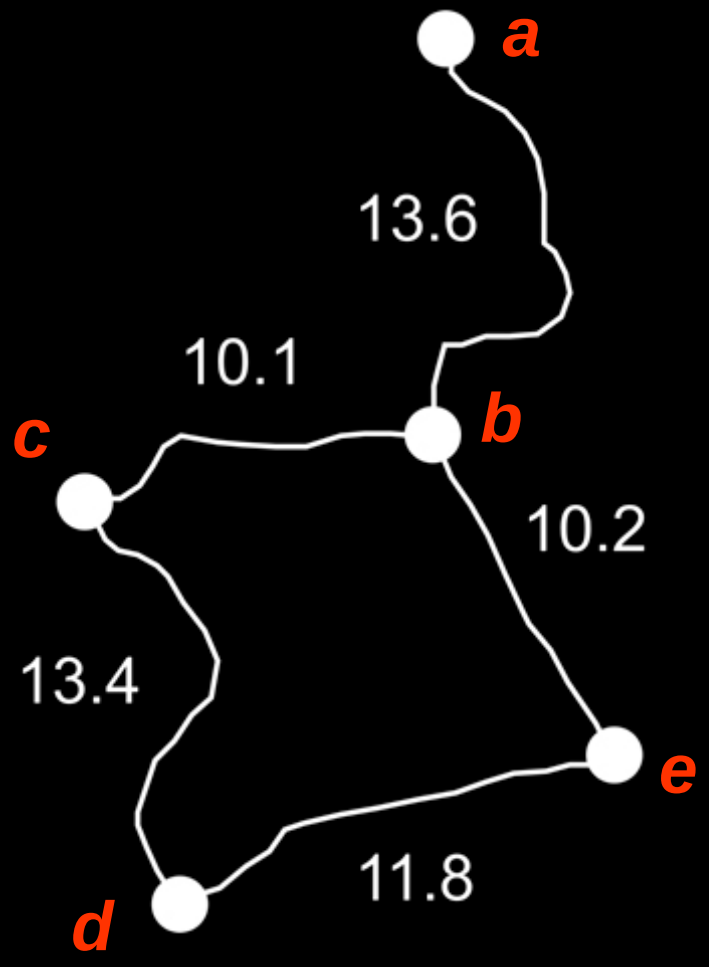
Just as with route circuitry, nodes can be mapped based on their circuitry.

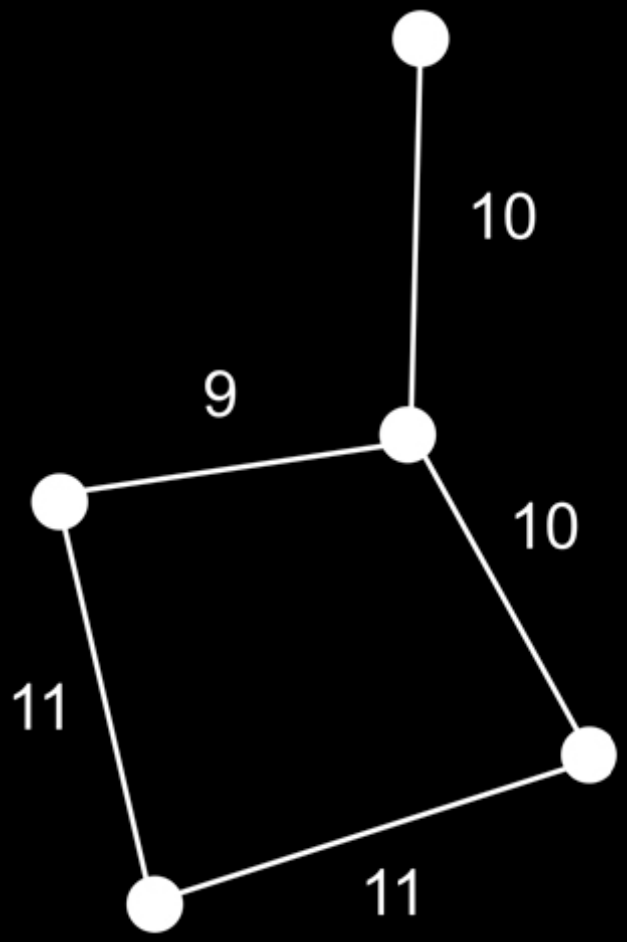
The circuitry of an entire network is calculated using the equation:

$$k_{network} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}(E_{ij} - d_{ij})^2}{n^2 - n}$$

This can be determined simply by creating a matrix of route circuitry values.

The original maps.





Remember to use the equation:

$$k_{ij} = \frac{(l_{ij} - d_{ij})}{l_{ij}}$$

	a	*b*	*c*	*d*	*e*
a	—	12.96	21.16	50.41	14.44
b	12.96	—	1.21	1.00	0.04
c	21.16	1.21	—	5.76	1.69
d	50.41	1.00	5.76	—	0.64
e	14.44	0.04	1.69	0.64	—

	a	*b*	*c*	*d*	*e*
a	—	12.96	21.16	50.41	14.44
b	12.96	—	1.21	1.00	0.04
c	21.16	1.21	—	5.76	1.69
d	50.41	1.00	5.76	—	0.64
e	14.44	0.04	1.69	0.64	—
Column Total:	98.97	15.21	29.82	57.81	16.81

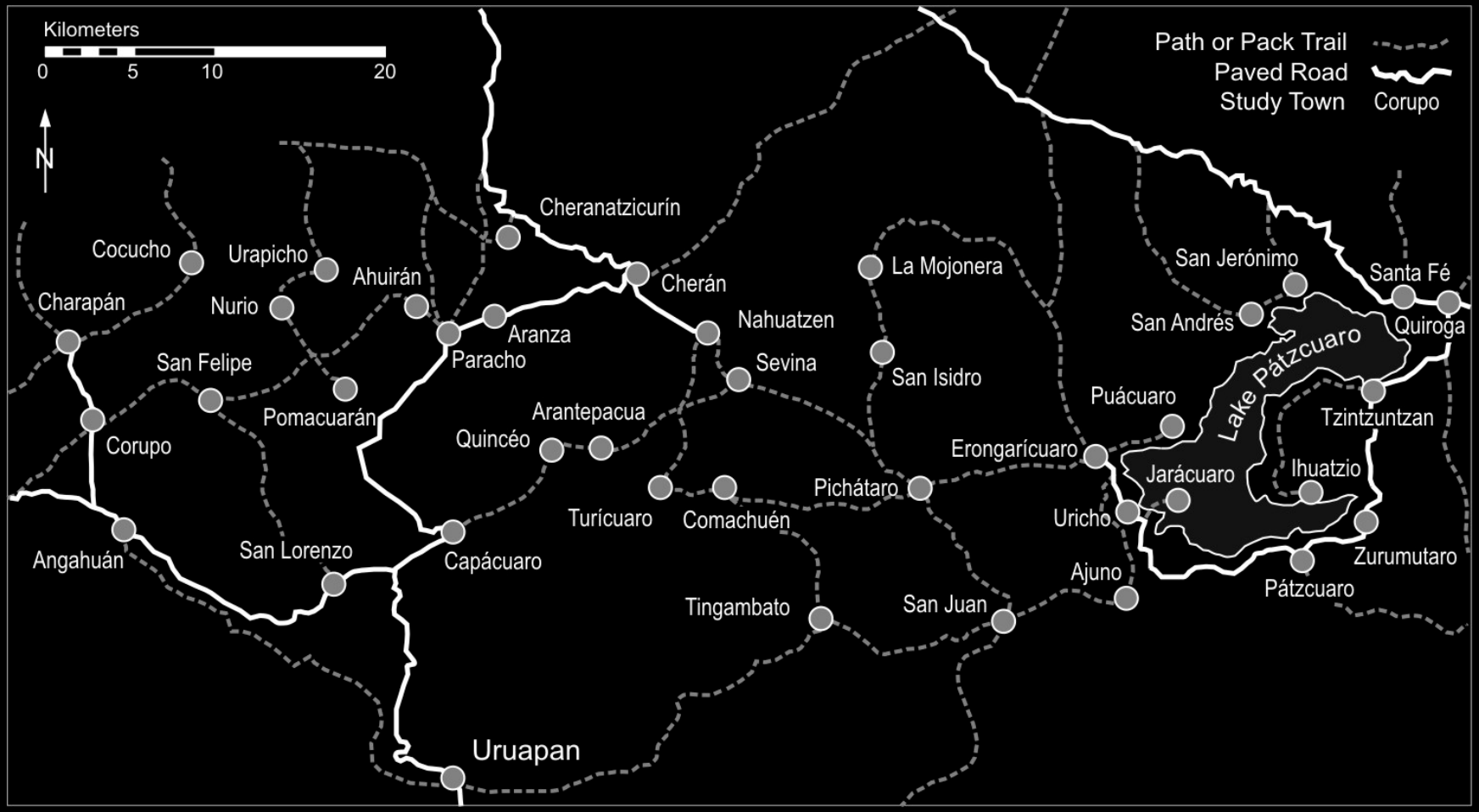
Grand Total: 218.62

$$k_{network} = \frac{218.62}{5^2 - 5} = \frac{218.62}{20} = 10.93$$

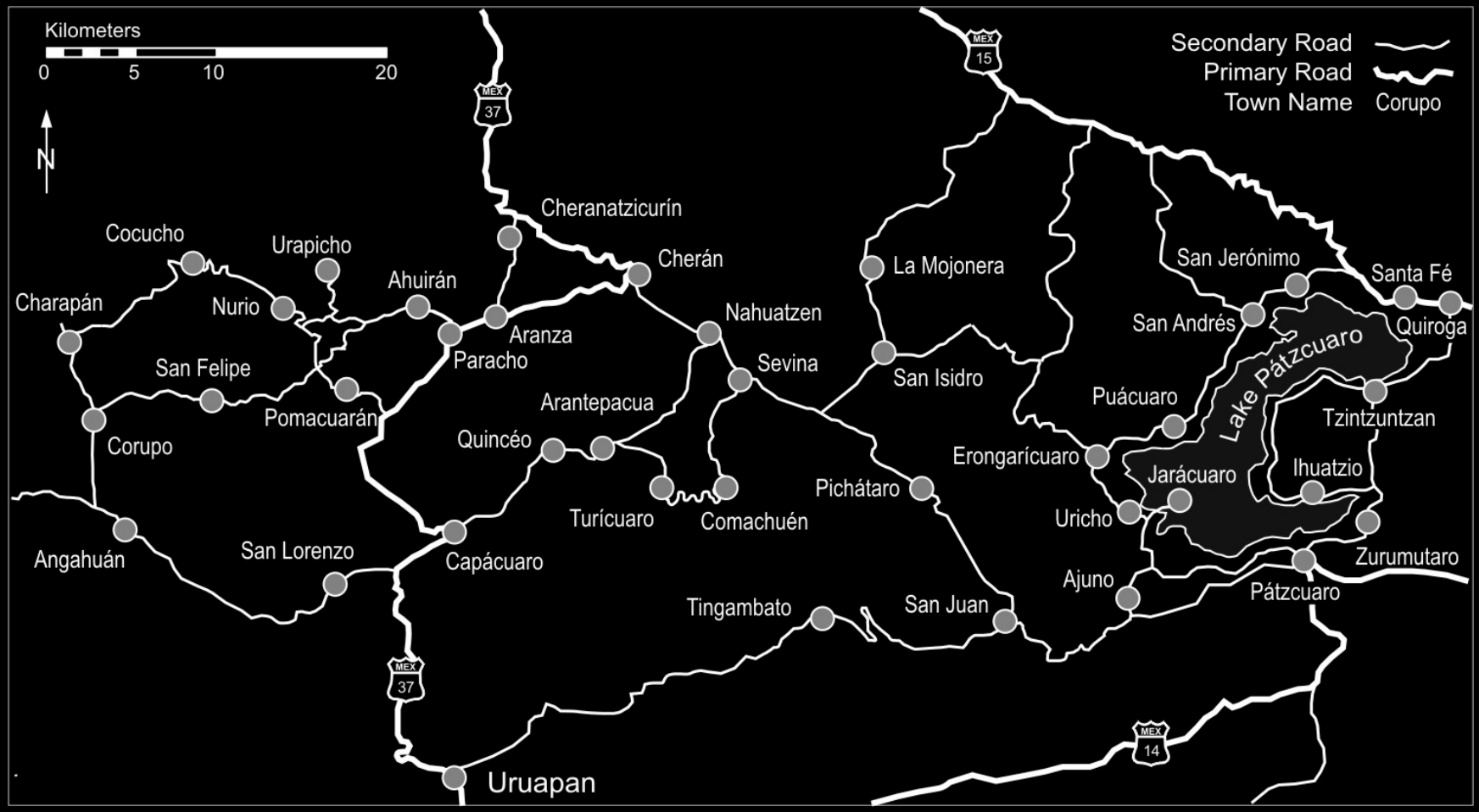
The following is an example of changes in accessibility after road upgrades and realignment.

The data are from Michoacán, Mexico.

Network: 1940



Network: 2000



Route Distance

Town Name	Ahuiran	Ajuno	Angahuan	Arantepacua	Aranza	Capacuaro	Charapan	Cheran
Ahuiran	0.00	51.40	27.22	29.77	6.07	19.17	22.50	15.01
Ajuno	51.40	0.00	67.95	34.96	35.56	46.96	73.85	36.50
Angahuan	27.22	67.95	0.00	32.85	33.17	20.92	12.40	42.31
Arantepacua	29.77	34.96	32.85	0.00	23.75	12.15	42.64	14.93
Aranza	6.07	35.56	33.17	23.75	0.00	17.78	28.51	9.13
Capacuaro	19.17	46.96	20.92	12.15	17.78	0.00	30.53	26.91
Charapan	22.50	73.85	12.40	42.64	28.51	30.53	0.00	37.58
Cheran	15.01	36.50	42.31	14.93	9.13	26.91	37.58	0.00

Geometric Distance

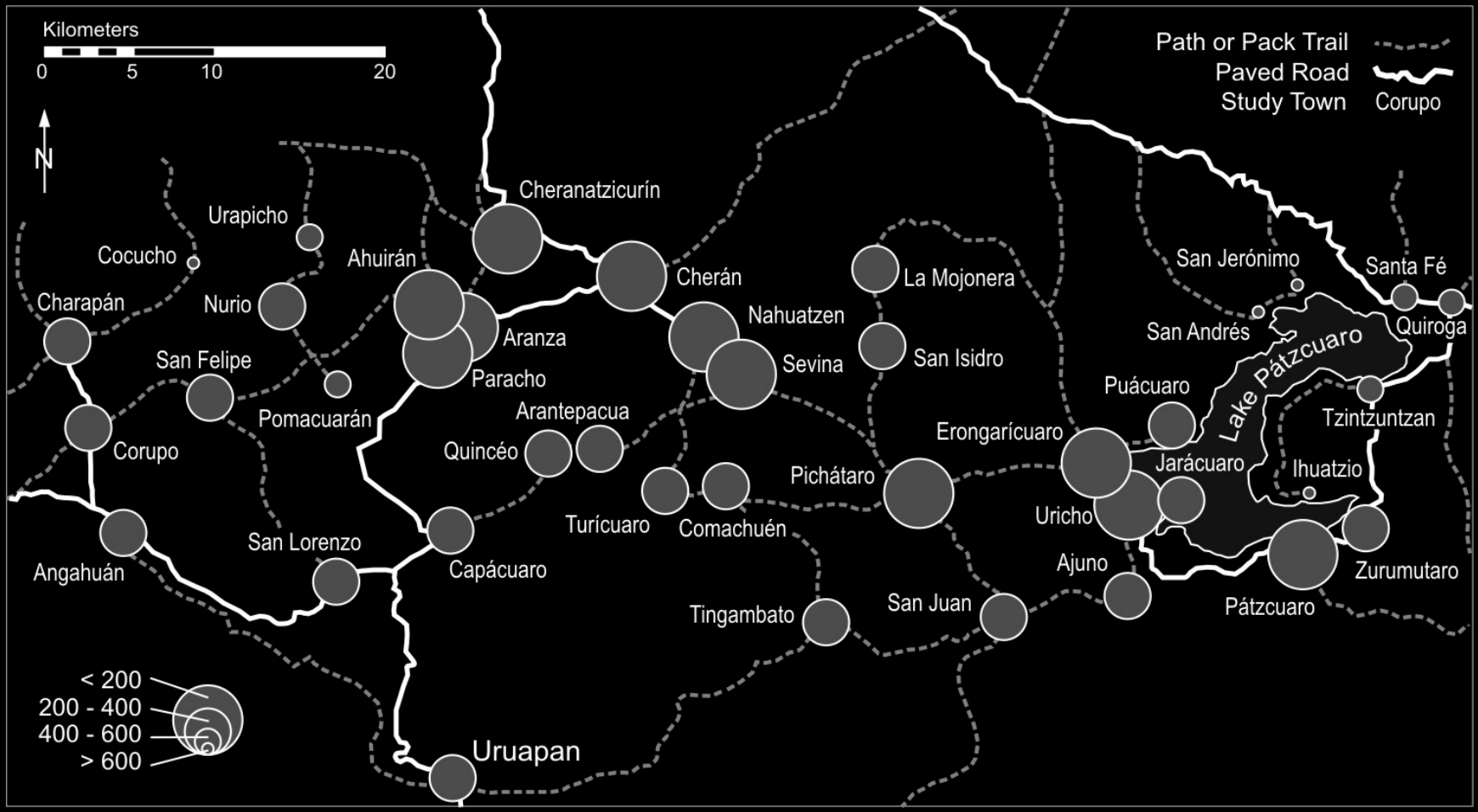
Town Name	Ahuiran	Ajuno	Angahuan	Arantepacua	Aranza	Capacuaro	Charapan	Cheran
Ahuiran	0.00	40.86	20.67	14.22	5.28	13.30	19.03	12.83
Ajuno	40.86	0.00	53.80	27.04	35.71	35.19	58.16	30.88
Angahuan	20.67	53.80	0.00	28.33	24.41	18.64	11.10	32.50
Arantepacua	14.22	27.04	28.33	0.00	9.59	10.55	31.22	10.20
Aranza	5.28	35.71	24.41	9.59	0.00	12.33	24.11	8.12
Capacuaro	13.30	35.19	18.64	10.55	12.33	0.00	24.02	18.29
Charapan	19.03	58.16	11.10	31.22	24.11	24.02	0.00	31.85
Cheran	12.83	30.88	32.50	10.20	8.12	18.29	31.85	0.00

$$k_{Ahuiran,Ajuno} = \frac{(50.40 - 40.86)}{40.86} = 0.268$$

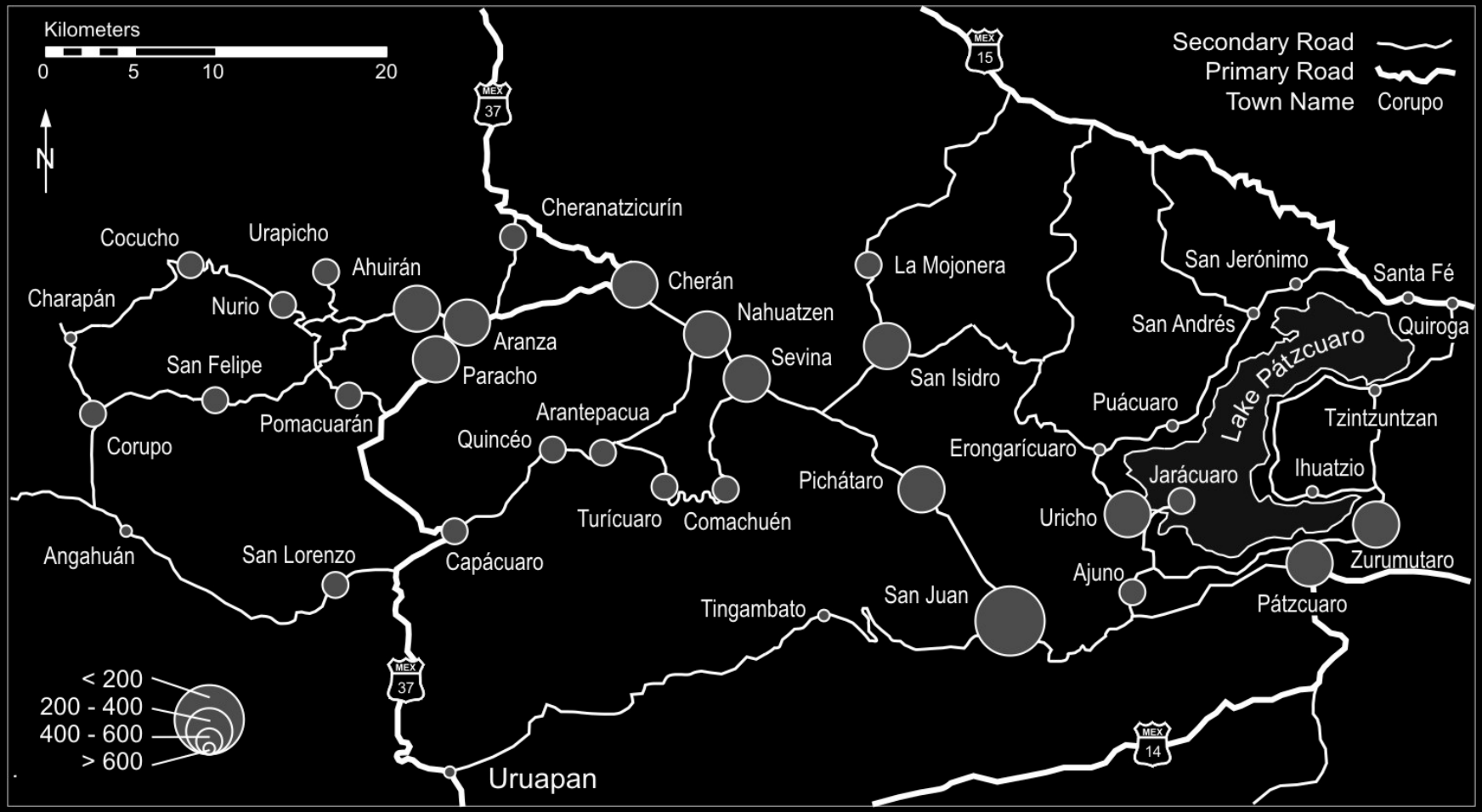
This is done for every cell in the matrix… for our 41x41 matrix, 1681 times. A subset is below:

Town Name	Ahuiran	Ajuno	Angahuan	Arantepacua	Aranza	Capacuaro	Charapan	Cheran
Ahuiran	0	26.8	7.2	26.6	30.3	82.5	187.2	263.1
Ajuno	26.8	0	0.4	23.3	21.7	13.2	188.1	153.0
Angahuan	7.2	0.4	0	0.8	1.4	16.4	23.4	60.9
Arantepacua	26.6	23.3	0.8	0	0.1	0.5	12.1	19.8
Aranza	30.3	21.7	1.4	0.1	0	0.1	0.3	33.8
Capacuaro	82.5	13.2	16.4	0.5	0.1	0	86.9	12.6
Charapan	187.2	188.1	23.4	12.1	0.3	86.9	0	411.9
Cheran	263.1	153.0	60.9	19.8	33.8	12.6	411.9	0
Totals:	624.1	426.9	110.9	83.3	87.8	212.4	910.2	955.5

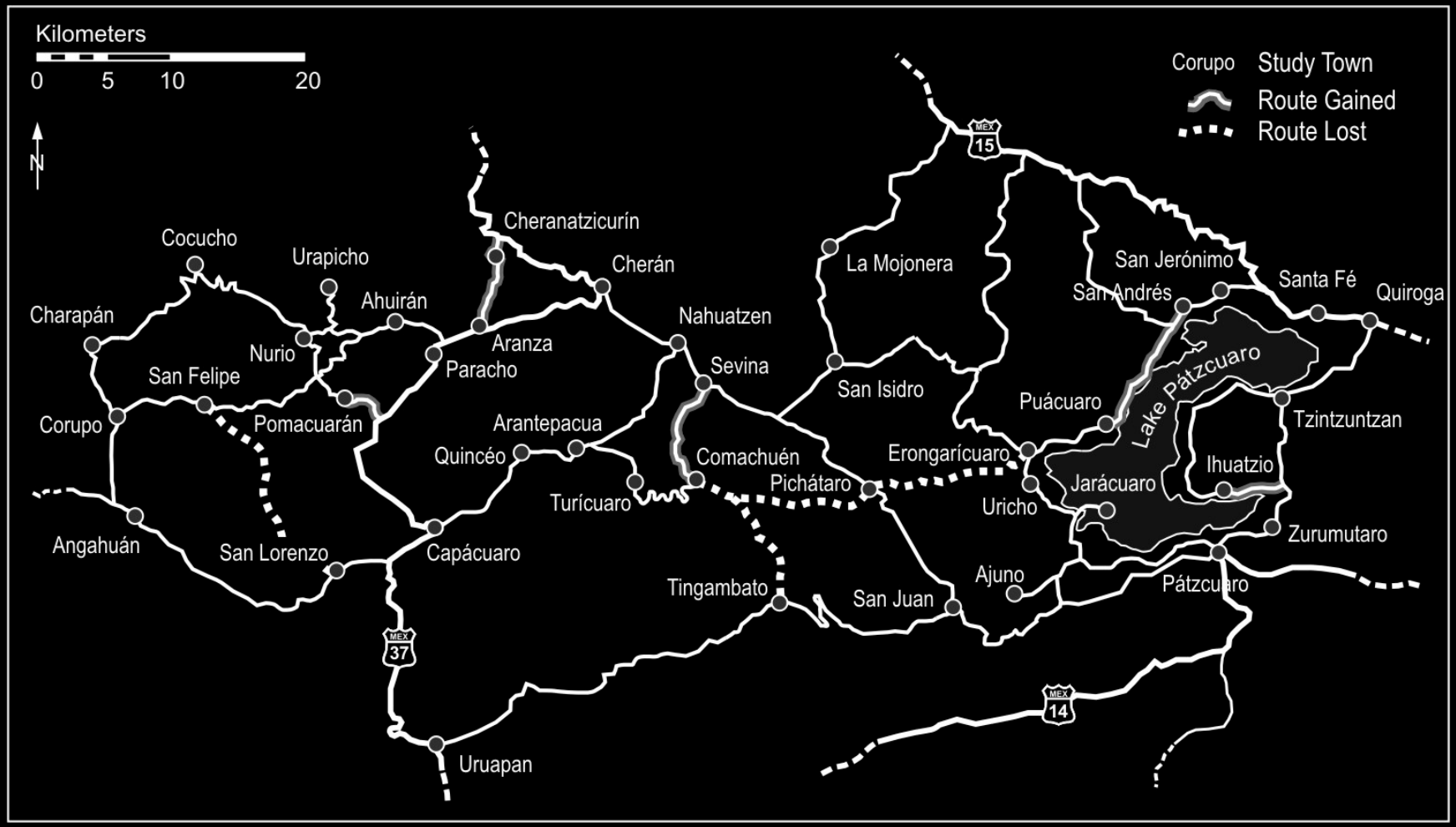
Circuity in 1940



Circuity in 2000

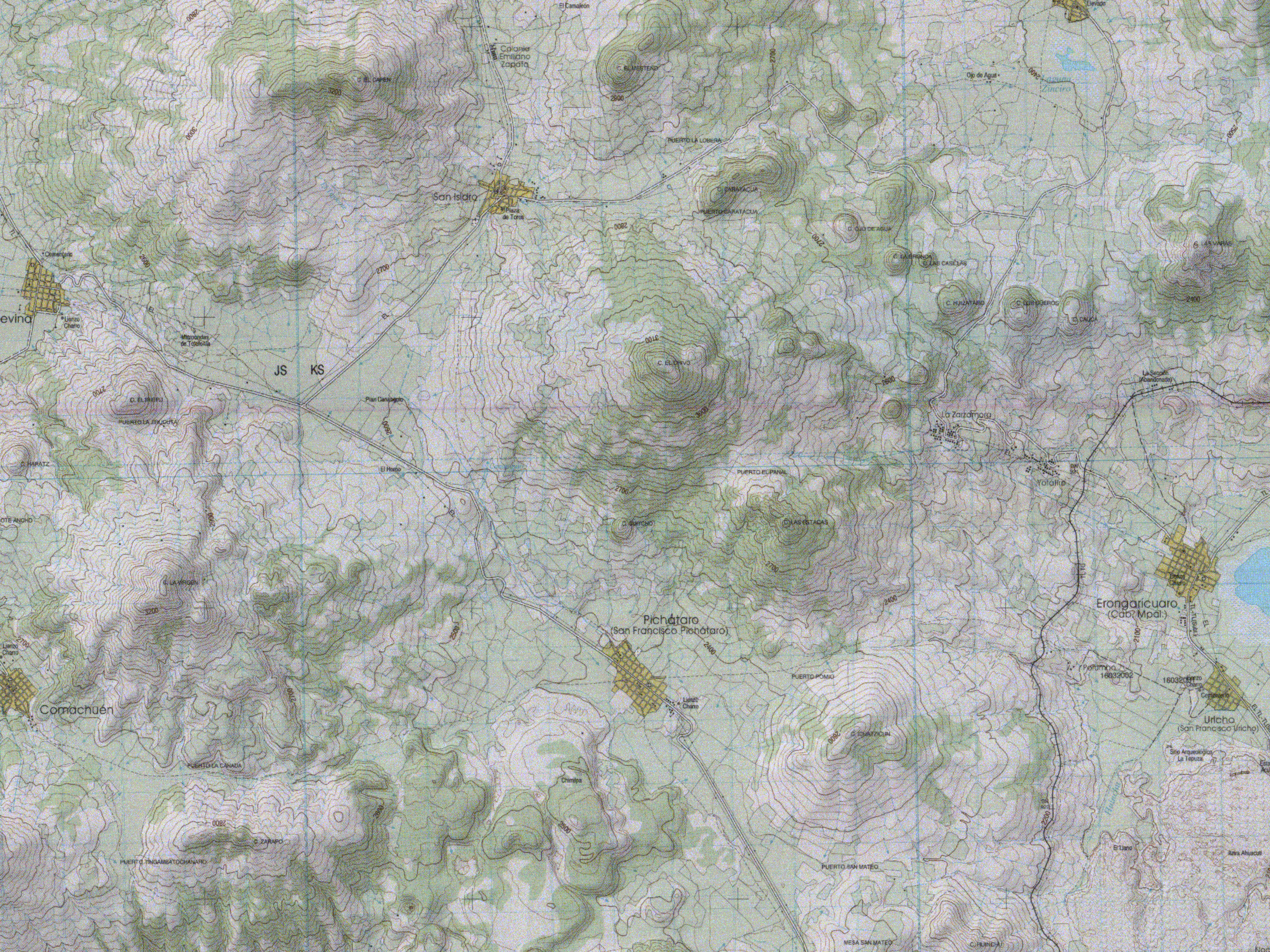


Important Route Changes, 1940-2000

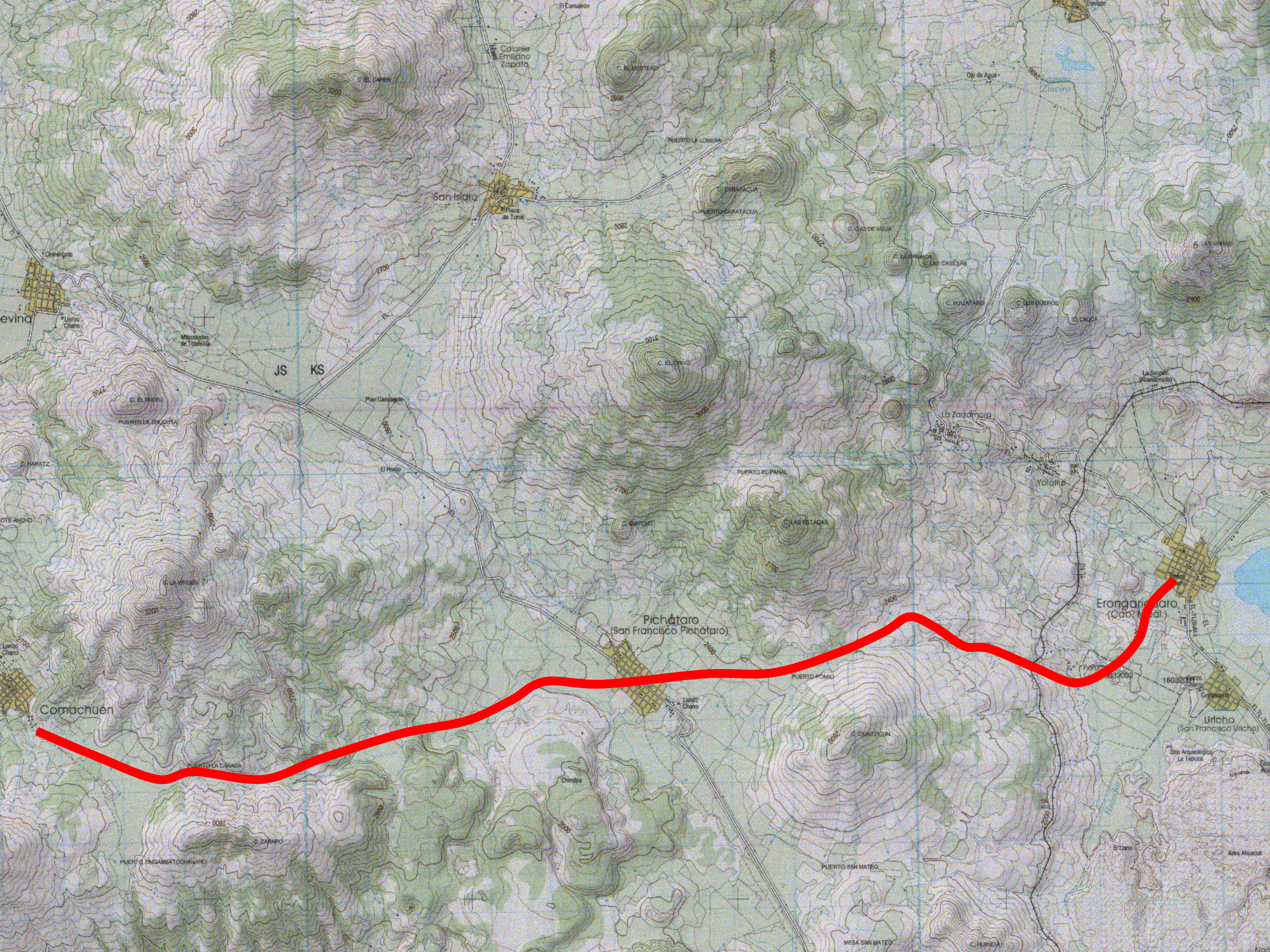


Circuitry Comparison
(based on total data set)

Settlement	*Circuitry40*	*Circuitry00*	*Change*
Ahuiran	181.33	388.88	46.63
Ajuno	206.06	424.13	48.58
Angahuan	222.03	714.76	31.06
Arantepacua	258.23	407.19	63.42
Aranza	167.47	352.45	47.52
Capacuaro	221.91	419.96	52.84
Charapan	240.00	623.30	38.51
Cheran	134.57	278.00	48.40



San Isidro
JS
KS
La Zarzamora
Yotatiro
Pichátaro
(San Francisco Pichátaro)
Erongarícuaro
(Cab. Mpal.)
Uricho
(San Francisco Uricho)
Comachuén
PUERTO EL PANAL
PUERTO POMIO
PUERTO SAN MATEO
MESA SAN MATEO
PUERTO LA CAÑADA
C. ZARAPO
El Hoyito
Plan Carabajo
El Llano



San Isidro
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