Structure and Requirements of the Transport Network of Syria

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•THIS STUDY examines the relationship between the spatial structure of a transportation network and other basic distributions reflecting the demands for transport facilities. These ideas are examined within the regional setting of Syria, a country carved out from the age-old Turkish Empire after World War I by somewhat arbitrary international boundaries, which disrupted old functional or nodal patterns and the well-developed flows of commodities and people associated with them. Measures of transport network structure are derived from graph theory, and are related by multiple regression methods to spatial variations in the distributions of population, economic activity, and the physical base. In this fashion the variables having a significant effect on transport network development are identified, and the variation in the growth of the network from place to place within Syria is described. This is followed by the identification of areas where a lag in the network development exists, based on the foregoing assumptions. These may be the areas where future development ought to be undertaken, especially in places where a high degree of growth in population and economic activity is taking place.

Graph theory techniques are also applied in the examination of changes through time of the total connectivity of a transport network and the relative connectivity of major urban centers. In this fashion, the important centers which decreased in connectivity due to the realignment of the network are identified, as well as newly emerging urban centers whose relative connectivity increase places them in an advantageous location on the major trunk lines of the developing network. This method of analysis is especially useful when examining increases or decreases in connectivity, or accessibility of urban places through time, due to the effects of superimposing an international boundary which severs the network at critical points, as is the case with a large number of developing countries, making it necessary to realign the network to meet the national demands of the country.

GRAPH THEORY MEASURES

In its natural form, graph theory is a body of mathematics which examines the relationship of points and linking lines. (For a detailed study of graph theory see Ref. 1.) In its adaptations to transport network analysis, the points may be considered the nodes of the network, and the lines as the road segments connecting the nodes. In this fashion, any network under consideration is reduced in shape from its actual form (Fig. 1a), to a simplified form, with its significant properties left intact (Fig. 1b). Thus graph theory, as applied in the area of transport network analysis, is a mathematical tool relating the vertices of the network to its edges. Since edges and vertices may be represented in a variety of ways, depending on the aim of the study, they have to be defined before the investigation. The vertices may represent urban centers in one study, whereas in another they may include any point where two lines intersect. Similarly, edges may be represented in many other ways. In one case they may represent the road (physical) connections, whereas in another they may represent distance or travel time between two points, whereas in still other cases they may be considered in terms of traffic flow.

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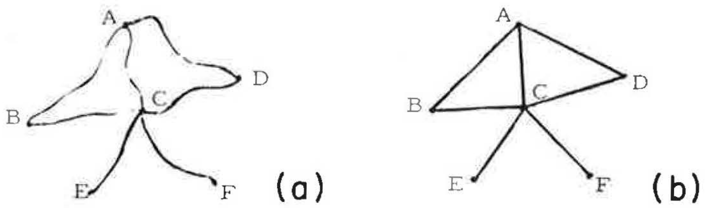
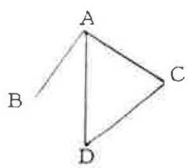


Figure 1. Transportation network: (a) actual form, (b) simplified form.



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

Figure 2. Matrix of connectivity.

Measures of Network Structure

The graph theory measure used in this study is the iota (2) index

$$i = \frac{M}{W + W_e}$$

where M is the total mileage of the network, W is the total number of vertices with weights assigned to them, and W_e is the number of weighted vertices in surrounding areas directly linked to the network. Two underlying factors are believed to influence the structure of the network: the first incorporates the idea that a connection to a first order vertex has a different effect on the system than a connection to a second or third order vertex. The second brings in explicitly the idea that the connections crossing the boundary lines from the surrounding units influence the structure of the network within the specific area under consideration. The weighting of the vertices is done arbitrarily with a value of 1 assigned to a first order vertex, a value of 2 assigned to a second order vertex, etc. The vertices, W_e, are similarly weighted.

Measure of Network Connectivity

Another fashion in which graph theory concepts are used in network analysis is to reduce the graph to a matrix of connectivity. This is done by constructing a matrix in which the vertices which are connected to one another are indicated by unit elements, and vertices that are not connected are indicated by zero (Fig. 2). The matrix may then be powered to the diameter of the graph, which is the minimum number of one-step connections required to join the farthest pair of nodes, and the connectivity of the different vertices is then calculated by totaling the rows of the matrix, and the hierarchy of the connectivity is determined.

This technique indicates the changes in connectivity over time, by examining basic measures of the structure of the network for any desired date, past, present, or future. This is based on the fact that as new connections are added to the graph, the value of the connectivity indices changes, not only that of the two vertices concerned, but those of the whole system.

Road Network Demands of Syria

For the purpose of this analysis, the 42 administrative divisions (Qada) of Syria are used as units, since all the statistical information gathered uses these units as the basis for data collection. Using the i index two sets of graph theory measures were obtained for each unit, one set representing the structure of the primary road network, and one set representing that of the road network as a whole. In addition to these dependent variables, the following eight independent variables, considered related to road network demand, are obtained: population index, agricultural index, industrial index, transit movement index, railroad competition index, size index, and slope index.

Multiple regression analysis is applied to the two dependent and eight independent variables after common logarithmic transformation was applied to the data. Table 1 gives the result of the multiple regression analysis, which is the relationship between each dependent and the eight independent variables, added one by one.

For example, the first row from left to right indicates that 1 percent of the total variation in the road network structure is statistically explained by the population distribution, 40 percent by agricultural production, etc., and, finally, 84 percent of the total variation is explained by the eight variables. One of the surprising results of the analysis was the low correlation between the structure of the network and the distribution of population. Investigation of this fact, however, reveals that in Syria there is a low degree of mobility among the majority of the people, which is one of the general characteristics of transportation in developing countries (3).

Agricultural production is highly correlated with road network reflected by the significant increase in R^2 when agricultural index is introduced to the analysis. This indicated the strong relationship between the agricultural sector, the most important economic activity in the country, to the pattern of the road network which links the areas of production to the local, national, and international markets.

The introduction of the index representing the industrial activity of the country provides a significant increase in the case of the primary network measure, but yields a relatively low increase for the total network measure. This result indicates that industry, in general, depends on primary roads more than it does on secondary and tertiary roads. However, this correlation is not as strong as in the case of agriculture, indicating that industrial production in Syria is still in its early stages of development.

The introduction of the index representing the movement of transit goods across the country has a very small effect on the coefficient of determination, reflecting the small correlation between movement of goods in transit, and network structure. This is mainly due to the fact that most of the transit goods passing across Syria are transported by rail, and have very little relationship to the development of the road network. Another reason for the low relationship may be due to the fact that Syria did not take the pattern of flow of transit goods into consideration in its recent development plans.

The index representing railroad competition results in a negative value of the regression coefficient which means that the presence of railways within a certain area is inversely related to road structure, portraying the competitive nature of roads and railroads. However, the inverse relationship is very weak, which may be due to a number of reasons:

1. Since the railroad system in Syria is very limited in extent, and is fragmented by political boundaries, competition is very small.
2. The measure of railway competition which took into account the presence or absence of rail lines may not have been the best way to examine the effect of railroads.

The introduction of the area index to the analysis brings about a large increase in the value of R^2 in both cases. This supports the fact that the size of a given area has a high relationship to the complexity of the network that develops within that area.

The shape index produced a negative value of the pertinent regression coefficient showing that a circular area, which has a low index value, requires a simpler network structure than an elongated area to serve its transport demands, other things being equal. However, once again the relationship was very weak and the value of R^2 did not increase much with the introduction of the index of shape.

The index of surface configuration is inversely related to the structure of the road network, which means that a rugged area has a simple network, whereas a flat area has a relatively more complex network. The increase in the value of R^2 after the introduction of the surface configuration index is significant, reflecting the importance of slope on the structure of a transport network.

Summarizing the results of the relationship of the network to the three major factors, i.e., population, economic activity, and physical base, it is evident that in the case of

Syria the economic and the physical factors are strongly related to network structure, whereas population distribution is weakly related to the country's network structure.

Analysis of Residuals from Regression

The expected values for each of the dependent variables were calculated, and then compared to the actual values of each entry. The difference between the two represents the residuals from regression. In the cases where the expected values are less than the actual ones, the residuals are negative, whereas in the cases where they are larger than the actual, their values are positive. The residuals are then broken down into five groups, using the standard error of the estimate as a criterion of classification, and plotted on maps (Figs. 3 and 4).

As the correlation between the dependent and the independent variables is high, it is appropriate to say that most of the important variables that are related to the structure of the road network in Syria have been identified, and incorporated into the study. Based on this assumption, the places that have low negative residual values can be identified as those places where there is a lag in the development of the road network structure, whereas the areas that have positive residuals are the ones that have a lead in the development of their road network. Analysis of the two residual maps reveals that there are a number of important districts which have a lag in both their primary and their total road network structure. Examples of such places are Al-Kamishli, Ain-en Arab, Ifrin, Banias, Feek and Homs. Other places have a lag in the development of their primary network, whereas still others have a lag in their network developments. Examples of the former case are Al-Latiquiya, Harem, and Ad Dijlah, and examples of the latter are Al-Hasakeh, Jarablus, Tartous, and An-Nabak. These results suggest that to enable the network to meet its transport demands, improvements in the structure of the road networks in these areas should be undertaken.

CONNECTIVITY OF TRANSPORT NETWORK OF SYRIA

Analysis of the connectivity of the transport network of Syria and changes in the accessibility of urban places through time is conducted in two parts: (a) connectivity of the railroad network; (b) connectivity of the highway network.

Connectivity of Railway Network

The first part of the analysis of the connectivity of the railway network is applied to the system as it originally developed, and the original important rail centers are identified. The second phase of the analysis examines the condition of the network after the introduction of political boundaries to the area, and the effects of this fragmentation on the individual centers. The third step analyzes the connectivity of the railway network by 1975, which includes the lines planned and under construction.

The matrix of connectivity is constructed and solved, and the percentage values for the relative connectivity of the major urban centers are obtained (Table 2). Homs, Damascus and Riyak have the highest indices of connectivity making them the most accessible urban centers to the network as a whole. These are followed by Dar'a, the main rail center in the south, and Hama and Aleppo, the important rail centers of the north. The rest of the centers have low indices of connectivity indicating their relative isolation from the overall network.

The international boundaries that came into being after World War I dissected the rail network leaving Syria with small sections (or in graph theory terms, sub-graphs) of the whole network.

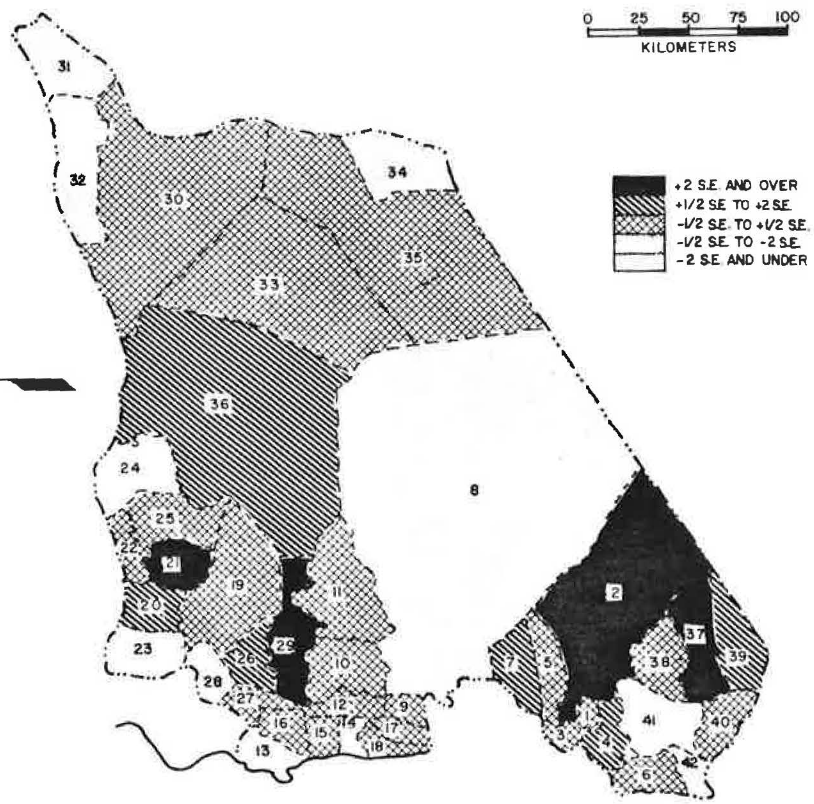
The matrix of connectivity for the present day rail network in Syria is constructed, and the connectivity values for each individual center obtained (Table 3). Aleppo and Hama became the best connected centers on the rail network, followed by Midan Ikbis and Choban Bey, then Homs, with the rest of the centers mostly isolated from the main system.

The connectivity of the rail network should increase significantly once the Aleppo-Al-Kamishli line, which is now being built, is completed, and when the proposed con-

TABLE 1

CUMULATIVE MULTIPLE COEFFICIENTS OF DETERMINATION

Dependent Variable	Population	Agriculture	Industry	Transit Movement	Railroad	Area	Shape	Slope
i (Primary network) R^2	0.01	0.40	0.46	0.46	0.47	0.79	0.80	0.84
i (Total network) R^2	0.003	0.34	0.37	0.38	0.38	0.80	0.81	0.88

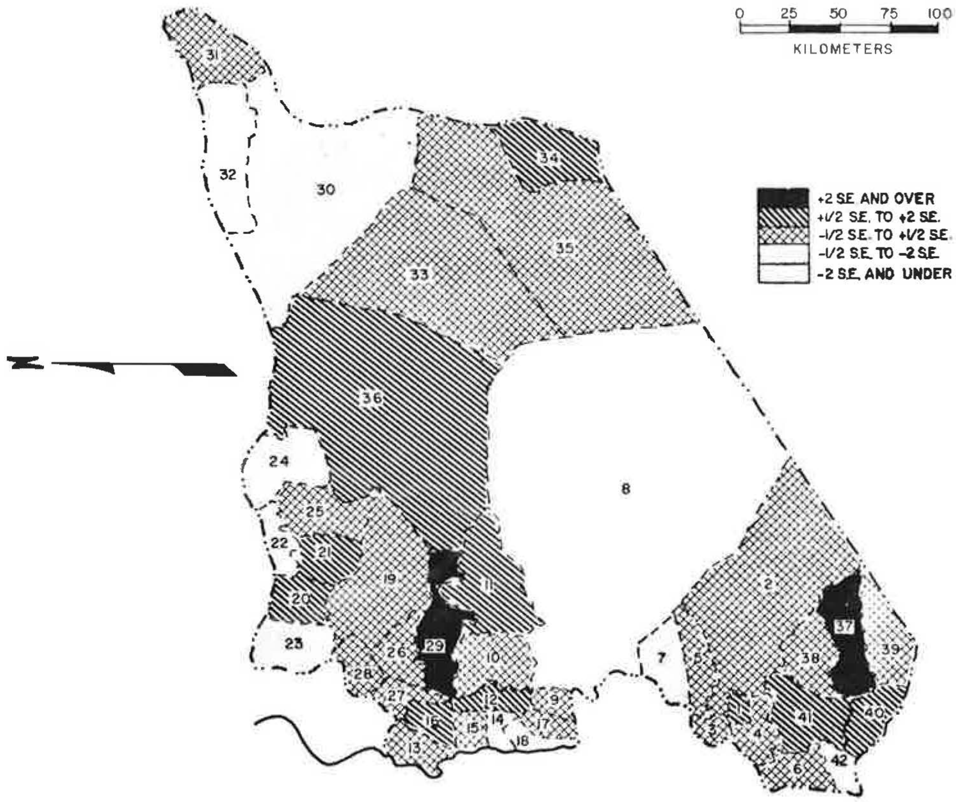


1. Damascus	11. Salamiya	21. Al Bab	32. Al Kamishli
2. Douma	12. Misyaf	22. Jarablus	33. Deir-ez-Zor
3. Zabadani	13. Al Latiquiya	23. Ifrin	34. Abou Kamal
4. Katana	14. Banias	24. Ain-el-Arab	35. Al Mayadin
5. Al Kteifeh	15. Jableh	25. Manbij	36. Ar-Rashid
6. Al Qneitra	16. Al Haffeh	26. Idlib	37. As Suweida
7. An Nabak	17. Safita	27. Jisr-esh-Shaghour	38. Shahba
8. Homs	18. Tartous	28. Harem	39. Salkhad
9. Tall Kalakh	19. Aleppo	29. Maarrat-en-Nouman	40. Dar'a
10. Hama	20. Izaz	30. Al-Hasakeh	41. Izra
		31. Ad Dijlah	42. Feek

Figure 3. Residuals from regression for the i measure of the primary road network.

nection linking Homs and Damascus is constructed. Table 4 indicates the connectivity values for the completed rail network.

Table 4 indicates that by 1975, Aleppo will have become the best connected center in Syria, lying between the important agricultural area of the northeast, the port of Al-Latiquiya and the large urban centers to the south. At that time, Rakkah, the second highest place of the connectivity scale, may very well become the regional center on the agricultural northeast, due to its favorable location between the small but important centers of Deir-ez-Zor and Al-Hasakeh on the one hand, and Aleppo on the other. The



1. Damascus
2. Douma
3. Zabadani
4. Katana
5. Al Kteifeh
6. Al Qneitra
7. An Nabak
8. Homs
9. Tall Kalakh
10. Hama
11. Salamiya
12. Misyaf
13. Al Latiquiya
14. Banias
15. Jableh
16. Al Haffeh
17. Safita
18. Tartous
19. Aleppo
20. Izaz
21. Al Bab
22. Jarablus
23. Ifrin
24. Ain-el-Arab
25. Manbij
26. Idlib
27. Jisr-esh-Shaghour
28. Harem
29. Maarrat-en-Nouman
30. Al-Hasakeh
31. Ad Dijlah
32. Al Kamishli
33. Deir-ez-Zor
34. Abou Kamal
35. Al Mayadin
36. Ar-Rashid
37. As Suweida
38. Shahba
39. Salkhad
40. Dar'a
41. Izra
42. Feek

Figure 4. Residuals from regression for the i measure of the total road network.

port of Al-Latiquiya, now without any rail connections, will have a relatively high connectivity value on the projected rail network. This will increase its accessibility to the rest of the country, both to the east and to the south, and will put it in a much better position to serve the shipping movements of the country. This will also give it a strong locational advantage over the port of Tartous, which is being renovated and enlarged, as this newer port will not have a rail line linking it to the rest of the country.

The connectivity of the rail centers in the south remains quite low and especially that of Damascus, the important urban and economic center of the area. This is in contrast with the position of Aleppo, the chief rival of Damascus, whose position relative to the developing rail network is very advantageous in its accessibility to Al-Latiquiya, the country's main port, and to the important agricultural region of the northeast, where the country's largest portion of export commodities comes from.

Connectivity of Road Network

This section analyzes changes in the connectivity of the road network in Syria and in the relative importance of the connections of urban places through time. This is done by first examining the network as it existed in the early 1920's, the first decade of mod-

TABLE 2

CONNECTIVITY VALUES OF MAJOR RAIL CENTERS

Center	Total Connectivity (%)
Islahiyeh	2.08
Midan Ikbis	4.78
Aleppo	8.27
Choban Bey	5.36
Nusaybin	3.25
Al-Kamishli	2.01
Tell Kotchek	0.90
Hama	8.31
Homs	11.22
Tripoli	4.52
Rivak	10.04
Beirut	5.21
Damascus	10.33
Dar'a	8.40
Haifa	5.11
Mafrak	5.11
Bosra	5.11

TABLE 3

CONNECTIVITY OF MAJOR RAIL CENTERS, 1963

Center	Total Connectivity (%)
Midan Ikbis	16.94
Aleppo	23.95
Choban Bey	16.94
Nusaybin	1.36
Al-Kamishli	1.36
Tell Kotchek	1.36
Hama	23.95
Homs	9.92
Damascus	1.36
Dar'a	1.36
Bosra	1.36

TABLE 4

CONNECTIVITY VALUES OF THE MAJOR RAIL CENTERS, 1975

Center	Total Connectivity (%)
Midan Ikbis	10.12
Aleppo	15.25
Al-Latiquiya	10.12
Choban Bey	10.12
Nusaybin	1.74
Al-Kamishli	2.61
Tell Kotchek	1.74
Al Hasakeh	5.16
Deir-ez-Zor	5.14
Raqqa	13.54
Hama	13.23
Homs	4.73
Damascus	4.06
Dar'a	1.48
Bosra	0.95

ern transport in the country, and by analyzing the present day network, and then interpreting the changes that have taken place.

In 1920, the beginning of the modern road network in Syria began to evolve. The network existing at the time had not been designed for motor use, but was a combination of improved caravan and wagon routes. The condition of the individual roads did not differ much from one another, so that in this phase of the analysis all connections will be assigned equal weights.

The matrix of connectivity for the road network existing in 1920 is constructed, and the percentage value of the 48 individual centers under consideration is then obtained (Table 5). High connectivity values are obtained for the major urban centers of Damascus, Homs, Hama, and Aleppo, and for the intermediate points of Jisr-esh-Shaghour, Idlib, and Maarrat-en-Nouman. It also shows the importance of Palmyra, Deir-ez-Zor and Rakkah, the eastern centers located on the important routes joining Syria and Turkey to places further east, such as Iraq, Iran, and then India.

Other results show the high connectivity of the southern centers where early economic growth, especially in the field of agriculture, took place. Most of the northern and northeastern centers, where very little development had taken place, had low connectivity values as did the port cities of Jableh and Tartous, whereas the port of Al-Latiquiya showed a moderate degree of connectivity.

TABLE 5

PERCENTAGE VALUE OF CONNECTIVITY OF URBAN CENTERS, 1920

Ain Deiwar	0.006
Karatchok	0.001
Tell Kotchek	0.006
Dmir Kabou	0.028
Al-Kimishli	0.127
Al-Hasakeh	0.562
Ras-el-Ain	0.201
Abou Kamal	0.517
Deir-ez-Zor	2.306
Rakkah	4.083
Tell Abyad	0.018
Ain-el-Arab	0.078
Manbij	0.331
Jarablus	0.313
Al-Bab	1.392
Aleppo	5.564
Izaz	1.318
Ifrin	0.312
Rajou	0.070
Harem	1.248
Idlib	5.809
Jisr-esh-Shaghour	5.023
Maarrat-en-Nouman	5.809
Al-Latiquiya	1.266
Al-Haffeh	0.285
Jableh	0.332
Banias	0.210
Kadmous	0.552
Misyaf	2.253
Hama	9.458
Salamiya	6.720
Homs	7.367
Safita	0.011
Tartous	0.049
Tell Kalakh	1.650
Palmyra	9.158
Douma	5.322
Damascus	7.095
Zabadani	1.609
Sab Biar	1.609
Shahba	2.011
Suweida	2.204
Salkhad	0.125
Bosra	0.547
Dar'a	0.125
Feek	1.609
Qneitra	1.609
Sheikh Miskin	1.609

TABLE 6

PERCENTAGE VALUE OF THE CONNECTIVITY OF URBAN CENTERS, 1963

Ain Deiwar	0.021
Karatchok	0.036
Tell Kotchek	0.133
Dmir Kabou	0.139
Al-Kamishli	0.323
Al-Hasakeh	0.657
Ras-el-Ain	0.319
Abou-Kamal	0.310
Deir-ez-Zor	0.874
Rakkah	1.514
Tell Abyad	0.644
Ain-el-Arab	0.311
Manbij	0.603
Jarablus	1.719
Al-Bab	0.886
Aleppo	5.783
Izaz	0.208
Ifrin	3.180
Rajou	0.075
Harem	1.327
Idlib	2.696
Jisr-esh-Shaghour	4.732
Maarrat-en-Nouman	3.606
Al-Latiquiya	2.570
Al Haffeh	2.020
Jableh	1.963
Banias	3.731
Kadmous	3.068
Misyaf	5.529
Hama	5.999
Salamiya	2.368
Homs	8.651
Safita	4.970
Tartous	7.304
Tell Kalakh	5.542
Palmyra	1.662
Douma	2.372
Damascus	3.321
Zabadani	0.818
Sab-Biar	0.464
Shahba	1.246
Suweida	1.583
Salkhad	0.650
Bosra	0.826
Dar'a	1.013
Feek	0.144
Qneitra	1.891
Sheikh Miskin	2.023

Between 1920 and 1963 the road network of Syria developed on a national rather than regional basis. The connections considered important were widened and improved, so that by 1963 the network was composed of primary, secondary and tertiary connections.

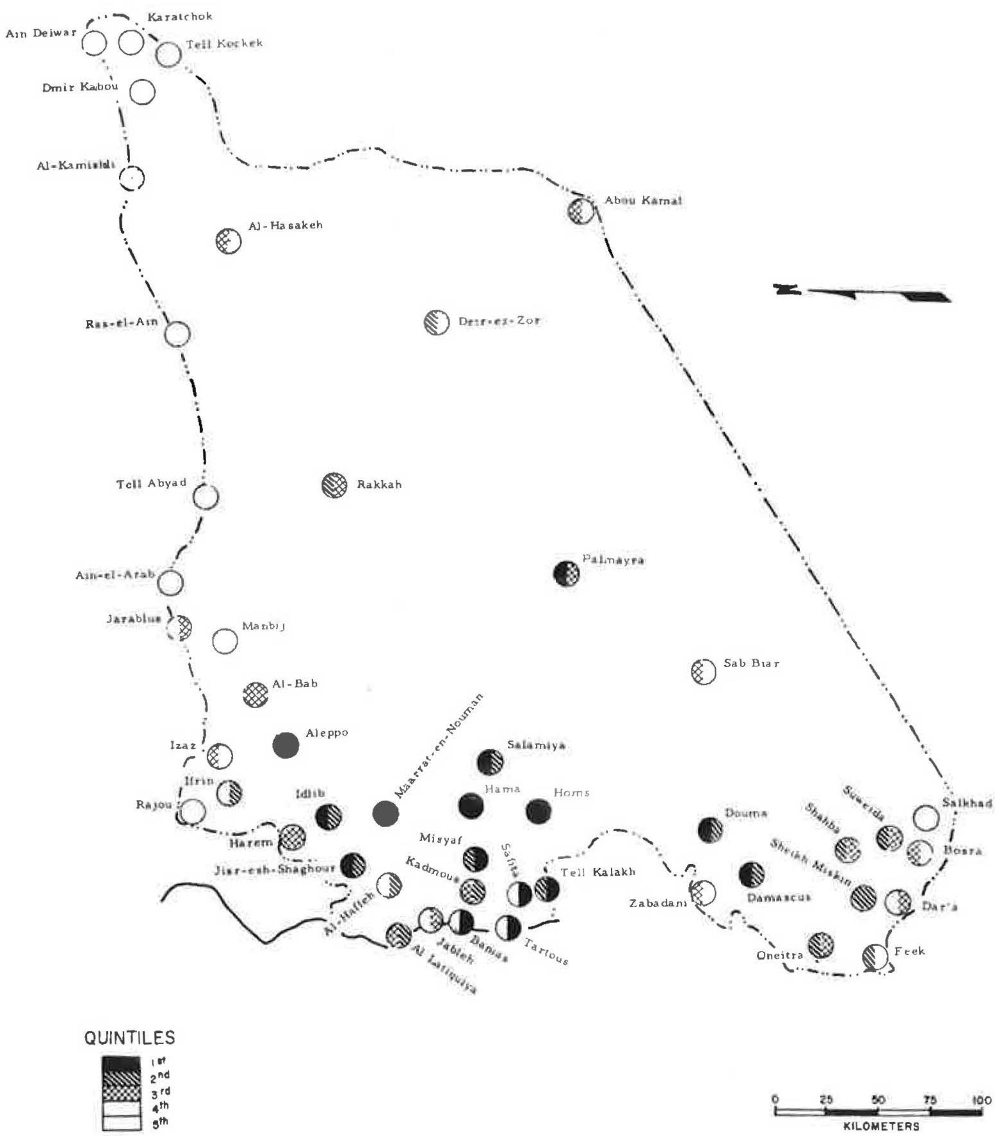


Figure 5. Connectivity value of the road network, 1920 and 1963.

In this phase of the anaylsis, weighting of roads is undertaken, so that a primary connection which is more important than a secondary or tertiary one, also has a higher index. The value assigned is done arbitrarily with a value of 3 given to a primary connection, a value of 2 given to a secondary connection, and a value of 1 given to a tertiary connection. Again the percentage values for each of the urban places is obtained (Table 6).

The first result obtained from the analysis is the large increase in the total connectivity of the network from 1920 to 1963. The second result is the fact that the connectivity of a number of urban centers increased between 1920 and 1963, whereas the connectivity index of certain other centers decreased in relative importance. This change is shown in Figure 5, where the left half of the circle shows the value of the relative weight of the center in 1920, and the right half shows the value of the relative weight of the center in 1963. One of the significant results in the analysis is the decrease in the connectivity in a large number of the urban centers in the southern part of the country, especially in the case of Damascus which went down from the first to the second quintiles. Another result shows the increase in the connectivity of the port cities of Al-Latiquiya, Jableh, Banias and Tartous, with Tartous having the highest degree of connectivity among the ports, even though Al-Latiquiya is the country's main port. Two significant facts were obtained from this information: (a) that Al-Latiquiya, which has become a busy port since its completion in 1960, handling over one million tons per year, is not as well connected to the areas that it serves as it ought to have been; and (b) the port of Tartous, in the process of being modernized and expanded, is well connected to the network, and would thus be in a relatively good position to serve the economy of the country and to provide the port of Al-Latiquiya with competition for handling the country's foreign trade.

Another result which is obtained from the analysis is that the connectivity of the eastern centers of Deir-ez-Zor, Rakkah, Abou Kamal and Palmyra decreased in the past 40 years. This is due to the fact that their early role as mid-points on transport lines linking the Mediterranean Sea to the regions further east, such as Iraq and Iran, was curbed and that they had become peripheral centers on a road network that developed on a national basis within the last two decades. The northeastern region as a whole is poorly connected to the rest of the country. This is a newly developed agricultural area where a large amount of the country's food supply, as well as most of its wheat and cotton for export, come from. Therefore, the regional urban centers where the agricultural products are gathered and then exported should become better connected to the areas of demand and to the port of export, so that speed of movement and decrease in transport cost could occur.

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