Theoretical Study of the Windsor Transportation Network

Robert Markovich

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A THEORETICAL STUDY OF THE WINDSOR TRANSPORTATION NETWORK

Robert Markovich
A THEORETIC STUDY
OF THE WINDSOR TRANSPORTATION NETWORK

ABSTRACT

Changes in the form of mass urban transportation seem to affect the size, shape and connectivity of public transportation networks along with the builder and user costs. At the same time variations in centrality can also be observed. This is particularly true when a more efficient form is substituted in an inefficient one. As may occur during a change from streetcars to buses.

This formula has been applied to the Windsor public transportation network for the years 1883, 1917, 1930, 1937, 1953 and 1968. In each case the results proved that the statements made above are correct.

Presented to
The Department of Geography

UNIVERSITY OF WINDSOR
1968
ABSTRACT

Changes in the form of mass urban transportation seem to affect the size, shape and connectivity of public transportation networks along with the builder and user costs. At the same time variations in centrality can also be observed. This is particularly evident when a more efficient form is substituted in place of an earlier one, as may occur during a change from streetcars to buses.

This formula has been applied to the Windsor public transportation network for the years 1893, 1917, 1930, 1937, 1950 and 1968. In each case the results proved that the statements made above are correct.
ACKNOWLEDGMENTS

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**FIG.** 9 Table of results following the application of the "Cyclostatic Number" and the "Beta Index".

**FIG.** 10 Use of Bunge's completely interconnected diagram after modifications.

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CHAPTER I

INTRODUCTION AND PURPOSE

The introduction of electric power on the Windsor public transportation scene was of considerable importance; it allowed greater speed over the existing networks, permitting a wider commuting radius, and extensions into areas which had been considered too remote during the horse-car days. However, electric transportation reached a climax during the twenties and began to decline when renovation and rehabilitation expenses, together with the rising costs of construction and the increasing popularity of the automobile, made further lines unprofitable. Therefore, a change to some better form of transportation became desirable, to the company and the public.

It is assumed here that the electric street railways, because of the tremendous amount of capital necessary for the construction of roadbeds and electric wiring, would begin as a type of system that would maximize the number of passengers within the shortest possible distance, since profit is always the foremost concern if any company is to remain in business. As a result, only clusters of population could be connected under these circumstances, preferably by a straight line, the shortest distance between any two points. Within the clusters where densities were greater, some extensions and branches could be installed
profitably, thus providing the residents with better service. However, this point will be handled in more detail in Chapter III.

As long as the same form of transportation remains, relative stability within the network may be expected. Stability means that very few major changes will occur in the pattern of construction and extension of new lines. However, once a new, more efficient form of transportation is adopted, a major change in the pattern might become apparent. Such an adoption may involve a conversion from streetcars to trackless trolleys, or to gasoline and diesel powered buses, as in the case of Windsor. The move would immediately allow greater versatility since rails would no longer act as a restriction. New routes could be established, offering profitable service in areas of much lower densities, leading to a belief that improved methods would provide greater accessibility, and consequently, better passenger service.

Therefore, it shall be the purpose of this paper to first, test the idea and establish, if and to what extent the Windsor system evolved from a 'least-cost-to-build, high-cost-to-use' network, into a 'high-cost-to-build, least-cost-to-use'. When referring to a 'high-cost-to-use' system, a number of factors may be considered, other than standard fares, since one may travel a considerable distance for the price of one ticket by transferring from carrier to carrier. One of these considerations is the
time factor, if one sets a value on each minute wasted in travel. Kansky's 'Beta Index', discussed in Chapter II, will be of great value in proving this theory.

Secondly, this paper will trace the development of the system and discover what effect the change from streetcars to buses had on the connectivity among the various points within the city and on their accessibility. Here, Kansky's 'cyclomatic number' will be useful, as it is an excellent measure of such problems. By applying a form of the 'associated' or 'König number', it is possible to get an idea of how this change affected the centrality of a number of locations, since connectivity and centrality are related. This will be done through a consideration of several time periods -- three during the streetcar era and two after buses took over. The last example of course, is the present day arrangement.

To achieve this purpose, William Bunge's 'minimization of distance' theories and K. J. Kansky's 'graph-theoretic measures of transportation', already mentioned, shall be employed and discussed within the second chapter in order that the reader may become familiar with the methods and techniques to be used. The succeeding chapter presents a brief history of the growth and development of Windsor's public transportation to the present. Some account is made here of the transportational factors which play a part in governing the growth and spread of cities. Finally, the theories described in Chapter II are applied to the problem and the necessary conclusions established.
A REVIEW OF THEORY

Considerable work has been done on theoretical models which can be applied to existing situations, making it possible to understand reality a little better. This work has been particularly significant in transportation and communication studies, since this is the life-line of any nation or developing region. Many of the models and measures developed have not been fully understood or fully applied.

Among the many graph theories produced, Bunge's minimum distance concepts and Kansky's graph-theoretic measures are probably the simplest to apply and the easiest to understand.

In his Theoretical Geography, Bunge presents five basic types of transportation networks which he feels are stages of evolution that various systems undergo from their early period of partial interconnections, Fig. 1, to their later stages, where all points are completely interconnected, Fig. 3-C. In so doing, "Bunge has drawn heavily on concepts of the most basic part of geometry and topology to illustrate the character of transportation networks." He points out that in establishing distance minimization problems, two assumptions had been made. First, it was concluded that the nearer cities or towns are to each other, the more interaction there will be among them. Secondly, he asserts,
"that the pattern of railroad networks depends on the ratio between the cost of using the networks and the cost of building it."²

By referring to diagrams 1 and 3, it may be noted that the vertices or points remain constant while the lines connecting them vary from figure to figure. First, the 'Soap-bubble' is an example of the shortest possible distance over which these points can be connected. The second, or the 'Travelling Salesman', demonstrates the shortest cyclical distance, while the 'Paul Revere' is a variation of the same. It leaves two points unconnected so that one may assume that they are the least important. The 'Hierarchy' problem, Fig. 1-D, shows the same five points. However, in this case, one of them has become a dominant or focal point, while the others act as satellites. Interaction is obviously stronger with the focal point and weakest among the satellites. This model is most likely to apply to new, emerging networks in small cities. In Fig. 2, the simplified diagram of 1893 Windsor closely resembles this pattern, with points of greatest density connected first. As population takes advantage of better transportation and begins to fill in the areas on either side of the arteries, interstitial lines become profitable and possible, encouraging growth at right angles to the radial lines. Figs. 7-A and 7-B are used to illustrate this process.

Although the models mentioned previously have certain advantages to the builder, they all lack interconnectivity,
BUNGE'S MINIMAL DISTANCE DIAGRAMS

(A) Soap Bubble

(B) Travelling Salesman

(C) Paul Revere

(D) Hierarchy Problem
WINDSOR, 1893

Diagram of Windsor, 1893

Sandwich

Windsor

Walkerville

Riding Park

BUNGE'S COMPLETELY INTERCONNECTED NETWORK

(Fig. 3)

(A)  (B)  (C)
and force the user to take often long round-about trips in order to reach certain destinations. This point is illustrated in the case of Fig. 1-C, where one must go completely around the circuit if he wishes to travel from A to B. However, as the networks develop, they will naturally tend toward an ultimate or final goal where all points are completely interconnected with all other points as in Fig. 3-C. On this basis Fig. 1 and Fig. 3-C become the two extremes that may exist in any urban unit. The more demand there is on a transportation network, the greater will be the density of lines and extensions. As the distance increases away from the focus or sphere of activity and as demand gradually decreases, "a 'least-cost-to-build' pattern will be favoured; between, there will be compromises in patterns."³

A useful yet simple method of testing the functional value (ability to connect areas and make them accessible) of any transportation network and its relative stage of development can be found through the use of the 'cyclomatic number' expressed as,

\[ H = e - v + p \]

where 'e' is the number of edges or routes, 'v' is the number of vertices or nodes, and 'p' is the number of non-connected sub-graphs,⁴ Fig. 4. This index has two important properties useful in transportation studies. First, the cyclomatic number, 'H', of a linear graph is equal to the maximum number of independent cycles of the graph. Secondly, in a connected graph, the cyclomatic number is
equal to the maximum number of fundamental circuits.\textsuperscript{5} 'Circuits', as used here, refers to a path from one point, around to several others and back again to the original point without retracing any of the routes. This is an indication that the value of $H$ may be used to measure the structure of networks and, at the same time, be correlated with geographical characteristics of areas. In Fig. 5, an almost completely interconnected graph has a value of 11 when the formula is applied. However, one might wonder why there is no connection between A and B. At first glance there seems to be no reason why this graph should not have a value of 12. On-the-spot investigation, however, may reveal a large lake, cemetery, or some other barrier between the vertices. According to Kansky, highly connected graphs have higher cyclomatic numbers, while the reverse is also true.

A superficial comparison of transportation networks of different countries would suggest that less developed countries are served by transportation systems which look more like disconnected graphs or trees. (For an example of the term 'trees' see Fig. 6.) In contrast, highly developed countries benefit from highly connected transportation networks. This similarity suggests that the cyclomatic number is a useful measure of the spatial structure of transportation networks.\textsuperscript{6}

The 'Beta Index', also a measure of connectivity can be applied to determine whether or not a network is a 'least-cost' or 'high-cost-to-build', and how quickly it is evolving in this direction. This index is expressed as,

$$B = \frac{e}{v}$$

where 'e' again relates to the number of edges, while 'v'
KANSKY'S USE OF THE CYCLOMATIC NUMBER

\[ H = 4 - 6 + 2 = 0 \]

(A) \hspace{1cm} (B) \hspace{1cm} (C) \hspace{1cm} (D) \hspace{1cm} (E)

\[ H = 0 \]
\[ H = 1.0 \]
\[ H = 2.0 \]
\[ H = 3.0 \]
USE OF THE CYCLOMATIC NUMBER IN EXPLAINING GEOGRAPHICAL CHARACTERISTICS
is the number of vertices. Transportation systems of a more complicated nature will boast higher values of 'B', while those having undergone less development will show correspondingly lower numbers. This index has one property which makes it particularly useful, the ability to record values from 0 to 3 in planar applications. (The non-planar application which will not be used here, records values from zero to infinity.) Here networks with one circuit have a value of 1. Disconnected networks on the one end and networks with two or more circuits on the other have values of less than 1 and more than 1, respectively, Fig. 6. Notice in Fig. 6 that the number of original edges has remained constant, while the vertices have decreased in number. Once the networks are joined, the vertices are considered to have overlapped one another, or to have become merged, since they are really endpoints of individual routes. As the number of such endpoints is reduced, the value of the entire system is increased. When the overall value goes up, it means that the connectivity is likewise increasing and, therefore, altering the 'least-cost-to-build, least-cost-to-use' ratio.

The final measure to be applied is the König number which, "Provides an understanding of the maximum number of edges from a given vertex to each of the other vertices." However, a reverse process may be applied, according to Forest R. Pitts in his Graph Theoretic Approach to Historical Geography. Pitts uses the minimum rather than the maximum
KANSKY'S USE OF THE BETA INDEX

By starting from A and counting the minimum number of intersections or edges in the network to all other points, a figure of B is obtained from A to A; 1 from A to B; 1 from A to C; 2 from A to D, and so on. (See chart, Fig. 8.) Once the chart has been completed, the sum is added from left to right and the values entered under the 'Total'. Each vertex will then have a number. If the vertices are now ranked on the basis of these numbers, some meaning that the first is the most central, while the others decrease in centrality according to their rank.

(A) Disconnected Networks

(B) Trees - Simple networks without circuits

(C) Networks with one circuit

(D) Networks with two or more circuits
number of edges from a given vertex to each of the other vertices in finding the measure for centrality. This method is demonstrated in Fig. 8, with the aid of an accompanying chart.

By starting from A and counting the minimum number of intersections or edges in the network to all other points, a figure of 0 is obtained from A to A; 1 from A to B; 1 from A to C; 2 from A to D, and so on. (See chart, Fig. 8.) Once the chart has been completely filled, each column is added from left to right and the values entered under the 'Total'. Each vertex will then have a number. If the vertices are now ranked on the basis of these numbers, some will emerge as being first, second, third, etc., meaning that the first is the most central, while the others decrease in centrality according to their rank.

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**FITZ’S USE OF THE KÖNIG NUMBER**

![Graph](image)

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3. Ibid., p. 187.


5. Ibid., p. 12.

6. Ibid., p. 12.

7. Ibid., p. 28.

Transportation in Windsor, even during earlier days, began as an inter-urban service, if such a term may be applied to the stage-coach. The nucleated settlements strung out along the river lacked any form of land communication, other than the stage, which particularly during the winter months, became the only link and source of news. Since stage drivers also acted as mail and newspaper distributors, they played an important part in the lives of the settlers. The term 'nucleated', or 'nucleus' as used here, "refers to any attracting element around which residential, business, industrial, or other growth takes place."\(^1\)

It is important to remember that Windsor did not spread out from a central core into its present boundaries completely on its own. Rather, it was the combined growth of Sandwich, Windsor, Walkerville, and later, Ford City and Riverside, which resulted in the final merger of 1934. Harris and Ullman feel that most cities have this beginning and that the tendency is not at all uncommon. Urban growth in most instances fills in around the centers to form a larger city.\(^2\) First there is radial development connecting the nucleated settlements with the dominant community, followed by growth along the township lines, Fig. 7.
EFFECTS OF TRANSPORTATION ON NUCLEATED SETTLEMENTS

Fig. 7-A

RADIAL DEVELOPMENT

ORIGINAL SETTLEMENTS

Fig. 7-B

INTERSTITIAL GROWTH

FUTURE INTERSTITIAL GROWTH

NEW URBAN GROWTH
When this growth becomes sufficient, interstitial or "cross-town" lines begin to appear further and further out from the center of the major city, Fig. 7-A. The example of Windsor clearly corresponds with Bunge’s ‘Hierarchy’ problem described in the previous chapter. That being the case, many transportation networks serving such expanding areas must have originated as inter-urban services and later changed to urban function. Since reference will be made to ‘urban’ and inter-urban’ transportation throughout this chapter, both terms should be properly defined. ‘Inter-urban’ refers to transportation systems connecting separate clusters, distinct both politically and geographically, while the term ‘urban’ refers to transportation systems operating within the boundaries of any one of these distinct units. Map I indicates the routes of the early stage lines. Much later, the Amherstburg-Sandwich streetcars followed an almost identical path as the stage coach.

Prior to the arrival of the Great Western Railway in Windsor, the tiny community was the least significant in relation to the others. Amherstburg and Sandwich had taken the lead long before, aided by certain site advantages which Windsor lacked. Amherstburg maintained the important role of a garrison town, controlling the main shipping channel into Lake Erie, while Sandwich, with its proximity to Detroit, together with the attraction of its mineral springs, had grown up as an administrative and recreational focus for the area. In addition, its central location with
Map 1

ESSEX COUNTY

STAGE LINES AND
NUCLEATED SETTLEMENT LOCATIONS - 1854

NUCLEATED SETTLEMENTS

STAGE LINES

0 5 10 MILES

WINDSOR
SANDWICH
AMHERSTBURG
BELLE RIVER
KINGSVILLE
LEAMINGTON

ESSEX
respect to Amherstburg and other Canadian settlements, as well as Detroit, helped to promote its dominance.

Nevertheless, with Detroit directly across the river, Windsor's locational advantages became apparent as soon as the railway arrived, allowing the community to benefit from the activities which the Great Western generated. For example, prominent Amherstburg and Sandwich citizens such as the Bartlets, Macdonnells, the Mercers, and many others, who had money to invest, moved to Windsor in anticipation of a forthcoming boom in prosperity when it became certain that Windsor was to become the rail terminus. They were not disappointed, for the community mushroomed from a mere three hundred in 1854 to over 2,000 in 1858, achieving town status during the same year. By 1872, it had nearly reached city-size, and was the largest settlement on the Canadian side. (Map II shows growth stages in Windsor.)

Though Windsor grew by leaps and bounds, Sandwich remained the administrative center for the county and the seat of the county court and jail. This meant constant movement between the two communities. Transportation under the existing road conditions was anything but pleasant. Therefore, the need for a more efficient inter-urban service became apparent, even though no such need existed within the town itself. In addition, the development of Sandwich into a resort spot of considerable prominence increased the need for transportation. A typical summer day witnessed as many as ten thousand people flocking into the area,
Map II

WINDSOR

STAGES OF GROWTH
1854 - 1968

TO 1854
1854 - 1872
1872 - 1934
1934 - 1966
W.E. & L.R. Co.,
1908 - 1932

MILES

0 5 10
mainly from Windsor and Detroit. Under these conditions, neither the stage nor the private liveries could be sufficient.

In response to this demand, the Windsor and Sandwich Railway Company was formed in 1872, connecting the two communities. The six horse-drawn carriages, capable of seating twenty persons each, moved over smooth metal rails, and far outshone all existing methods (Map III). Because the line had been surveyed and constructed, "through the fields", separating the two locations, it can by no means be considered an urban line. However, as soon as the service was introduced, land values on either side began to rise. Residential and social functions quickly emerged, bringing with them considerable commercial growth in areas where cars stopped to pick up or discharge passengers. Norman D. Wilson explains that this too is a common pattern. With improved capacity and increased speed, the commuting distance widened appreciably. Thus, the horse-car extended the half hour travel from one and one quarter miles to two and one half miles.

Suburban villages, previously in every sense distinct communities, became merged in the greater city. A less dense, more open development of cities occurred, and since fully twice, if not four times, the area formerly available for building within the sixty-minute zone was now available.

An electric line constructed in 1886, the Windsor-Walkerville Passenger Railway, produced a comparable effect. Restricted by the Great Western's railyards, and the industrialized waterfront, residential development, however,
remained on the south side of Sandwich (Riverside Drive). Although passengers could transfer from one line to another, the lines remained distinct, providing an example of Kansky's 'disconnected networks'.

Following this experiment, transportation development remained stagnant. Coinciding with a period of economic depression, the two roads fell into disrepair and continued to deteriorate until bought out in 1891 by American interests, which joined and renamed the lines to form the Sandwich, Windsor and Amherstburg Railway Company (SW&AR). The entire system was rehabilitated and electrified, old roadbeds repaired, overhead wiring replaced, and new coaches ordered. By the end of 1892 electric streetcars operated directly between Walkerville and Sandwich. Two additional extensions appeared the following year; one along Riverside Drive from Ouellette to Campbell, then south to London Street (University Street); the second, south along Ouellette to Riding (Jackson) Park, a popular race track of that time (Map III).

By 1901 the ownership changed again, marking a significant step in the development of Windsor's transportation. The new owners, Detroit United Railway Company, influenced by the rapid growth of electric inter-urbans in their own country, began to apply the same principle in Canada.

With the invention of the modern railroad motor in 1884 and the overhead trolley in 1887, the electrically driven streetcars rapidly replaced the horse drawn cars in larger cities. By 1902, 97 per cent of American streetcars were electrically powered
and considered to be the best means of locomotion for mass urban transportation. Consequently, under their influence, a Windsor-Amherstburg line was opened in 1903 and a Tecumseh line four years later (Map IV).

During the same period (1908), other interests applied for, and received permission to build and operate a line, the Windsor, Essex and Lakeshore Railway Company, from Windsor to Leamington, via Essex and Kingsville (Map II).

These events clearly correspond with the period of tremendous optimism for the electric inter-urbs in the United States. Investment reached such a pitch in that country, that lines introduced into certain areas had not the slightest economic justification for their existence. However, so long as revenue continued to climb, this lack of judgment went unnoticed. On the other hand, "When the farmer and the suburban commuter acquired the private car, inter-urban revenue declined rapidly." 15

Although the automobile had been on the scene for some time prior to the twenties, it had often been considered as a nuisance and a luxury item, and therefore its usefulness was neglected. Part of the reason lies in the early auto's lack of dependability, making it a machine suitable only for the young and the adventurous. 16 Not until World War I, were its possibilities really tested. With the development of the supply truck, short hauls became possible, both for men and supplies. Thus, with the termination of the war, motor transportation began to threaten
the electric systems. During the depression of the thirties, unemployed car owners in United States turned to carrying passengers in the busy downtown, skimming the cream from the profits of the public transit companies, who operated unprofitable outlying routes on the strength of the downtown runs. The 'jitney' as it was called, became outlawed in many areas, but not before it left its mark and weakened the structure of public transportation in many cities.

Even though Windsor escaped many of these processes, motor transportation, nevertheless, became increasingly important. Since Windsor was the site of the Ford Motor Company of Canada from 1904, as well as other automobile plants, the residents of the city enjoyed less expensive products and faster service than the rest of Canada. Prospects had been bright during 1914 when the Ontario Hydro Commission accepted the offer to manager the network following the 'Hydro Electric Railway Act' of the same year. After a short period of advancements and prosperity, the road began losing money and fell into disrepair, forcing the Hydro Company to abandon it as a money losing proposition by the end of 1934. Detroit, on the other side of the river, was experiencing similar difficulties and had spent considerable sums of money in an attempt to find a solution. In general, one of two things could be done -- either rehabilitate the existing equipment, or convert to another form. By this time buses had become recognized as an acceptable method for moving urban masses. In addition,
trackless trolleys or trolley-buses had been employed extensively across Canada and the United States. During the twenties, Windsor had tried the latter, but found it to be just as inflexible as the streetcar. (Map V outlines the routes followed by the short-lived trolley-bus.) Benefiting from the research in Detroit, Windsor decided that its own electric system was in such a state of neglect that it would cost less to purchase a new fleet of buses than it would to rebuild the existing lines. Furthermore, the advantages promised by a more versatile motor operation offered additional incentive. 19

Once a decision had been reached, progress was swift. During the first half of 1938, streetcar service ended along the less profitable Amherstburg and Tecumseh routes, but was replaced by the new motor coaches. Substitution continued in quick succession as additional buses became available. Thus, by the end of 1938, only the two busiest runs still remained. However, even these were replaced the following year. 20 A period of testing and readjustment followed as new routes were installed and old ones modified or discontinued, until the most satisfactory pattern had been achieved, 21 (Map VII). Today, the network is not much different from that of 1950. Many of the routes are still the same, aside from expansion in the southern portions of the city, and the suspension of service to Tecumseh and Amherstburg in 1956 and 1958 respectively (Map VIII).
REFERENCES


4. Ibid., p. 88.

5. MacDonald Historical Collection, Hiram Walker Historical Museum. Unit 20-135-115-5.

6. Ibid., Unit 20-135-40.


11. Ibid.


21. Ibid.

Cyclomatic number were applied to each individual time period (1893, 1917, 1937, 1950 and 1968). In both cases, values rose slowly but steadily between 1893 and 1930. However, the next seven years witnessed a drastic reduction in values, as well as reduction in the number of edges and vertices, clearly indicating a reduction in service. Since the period corresponds with the general eclipse of electric transportation across the continent, Windsor's attempts to cut costs by eliminating less profitable lines, are understandable. One may assume that the streetcar had outlived its usefulness and was beginning to experience a rapid decline, forcing the network back toward a 'least-cost-to-build' condition.

The subsequent conversion from streetcars to buses solved the problem. From the end of 1939, when the last electric car went out of service, to 1950, the topological extent of the system more than doubled. (Compare maps VI and VII.) At the same time the value of 'H' jumped from 2 to 21, while the Beta Index reflected a similar increase. Fig. 9. Higher numbers here indicate that bus substitution in place of streetcars allowed a higher level of economy, and thus permitted a greater density of routes. This hom-
CHAPTER IV

APPLICATION OF THEORY AND CONCLUSION

In the final analysis, both the Beta Index and the Cyclomatic Number were applied to each individual time period (1893, 1917, 1937, 1950 and 1968). In both cases values rose slowly but steadily between 1893 and 1930. However, the next seven years witnessed a drastic reduction in values, as well as reduction in the number of edges and vertices, clearly indicating a reduction in service. Since the period corresponds with the general eclipse of electric transportation across the continent, Windsor's attempts to cut costs by eliminating less profitable lines, are understandable. One may assume that the streetcar had outlived its usefulness and was beginning to experience a rapid decline, forcing the network back toward a 'least-cost-to-build' condition.

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ever, is to be expected and may be considered as proof of the obvious. On the other hand, the 1968 sample reveals something that is not obvious at all. Although the actual number of edges and vertices in 1968 had increased above 1950, the proportionate increase of edges over vertices remained less than required to maintain the earlier figure. Therefore, connectivity today has actually decreased slightly, even though the Cyclomatic Number shows a rise of three digits during the same period. This may be a hint that a second reversion to a 'least-cost-to-build' arrangement is about to take place. Although it is much too early to tell, it may also be an indication that buses are becoming less and less capable of handling the needs of a modern urban center. However, this is not the question. The purpose is, firstly, to establish whether or not Windsor transportation evolved from a 'least-cost-to-build' network into a 'least-cost-to-use'. Since the Beta Index, ranging from 0 to 3, is a measure of this evolution, the increase from .833 to 1.476 between 1893 and 1950 proves that the network did so evolve. Some method for judging just what such an increase means, should be employed. In this case, Bunge's diagram seems ideal for the purpose. His Fig. 1-D, with a computed value of .75, if placed at the bottom end of the scale and Fig. 10-B, illustrating the opposite situation with a value of 2.0 offers a reasonable range. Although vertices were inserted at the points of intersection in Bunge's diagram, it was found that the ratio of equation was not altered.
APPLICATION OF THE BETA INDEX AND THE CYCLOMATIC NUMBER

<table>
<thead>
<tr>
<th>CYCLOMATIC NUMBER</th>
<th>YEAR</th>
<th>BETA INDEX</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H = e - v + p$</td>
<td>1893</td>
<td>$\frac{e}{v}$</td>
</tr>
<tr>
<td>$= 5 - 6 + 1$</td>
<td></td>
<td>$= 5/6$</td>
</tr>
<tr>
<td>$= 0$</td>
<td></td>
<td>$= .83$</td>
</tr>
<tr>
<td>$H = 17 - 15 + 1$</td>
<td>1917</td>
<td>$\frac{17}{15}$</td>
</tr>
<tr>
<td>$= 3$</td>
<td></td>
<td>$= 1.13$</td>
</tr>
<tr>
<td>$H = 28 - 24 + 1$</td>
<td>1930</td>
<td>$\frac{28}{24}$</td>
</tr>
<tr>
<td>$= 5$</td>
<td></td>
<td>$= 1.16$</td>
</tr>
<tr>
<td>$H = 22 - 21 + 1$</td>
<td>1937</td>
<td>$\frac{22}{21}$</td>
</tr>
<tr>
<td>$= 2$</td>
<td></td>
<td>$= 1.05$</td>
</tr>
<tr>
<td>$H = 62 - 42 + 1$</td>
<td>1950</td>
<td>$\frac{62}{42}$</td>
</tr>
<tr>
<td>$= 21$</td>
<td></td>
<td>$= 1.476$</td>
</tr>
<tr>
<td>$H = 72 - 49 + 1$</td>
<td>1968</td>
<td>$\frac{72}{49}$</td>
</tr>
<tr>
<td>$= 24$</td>
<td></td>
<td>$= 1.469$</td>
</tr>
</tbody>
</table>
Map III-A

WINDSOR, 1893, STYLIZED
When compared, the 1893 Windsor diagram of 0.833 corresponds closely with Fig. 1-D, while the 1968 diagram of 1.469 is considerably below what has been taken as an example of complete interconnectivity, and further yet, from the value of 3. Even though the network has definitely evolved, it has not reached the optimum.

At the same time one may ask if the optimum can be reached at all? Following considerable experimenting with edges and vertices, it appears that the highest number which can be reached is 2.999 because the ratio never becomes proportionate enough to allow the value of 3. Fig. 11, with equation of $B = \frac{22}{9}$ computed at 2.6 points to this, while a more elaborate equation, not shown, but worked out mathematically, resulted in $B = \frac{896}{301} = 2.9$. In the non-planar applications, Kansky states, the range is from zero to infinity, while in the planar it is from zero to three. Since infinity cannot be reached, by the same token, the planar extreme of 3 should not be attainable either.

Since the diagram presented in Fig. 11 is only theoretical, and does not represent a feasible pattern of transportation, 2.4 would probably be impossible to reach in reality. However, one interesting fact did appear; in both equations higher values were reached only after the introduction of circular links between existing vertices, possibly indicating that connectivity can be raised only through the use of express routes and circumferentials over the present level. This appears to be the case in Windsor
(Fig. 10)

USE OF BUNGE'S COMPLETELY INTERCONNECTED DIAGRAM AFTER MODIFICATIONS

(Fig. 11)

A HYPOTHETICAL TRANSPORTATION NETWORK
and may account for the decline between 1950 and 1968.

Secondly, the tremendous jump from 2 to 21 between the years of 1937 and 1950, Fig. 9, proves that the change from streetcars to buses did result in greatly improved connectivity through the extension of existing routes and the addition of new ones. By looking at these maps, along with that of 1968, it may be noticed that the 1937 map has very few cross-town lines but a good deal of radial development. In 1950, this is no longer the case as interstitial growth begins to increase.

Finally, the application of the centrality index did not result in any particularly clear-cut observations. Centrality figures were worked out for each of the periods shown in Maps III-A to VIII-A, except for the 1930 map, because the time difference between it and 1937 was not great enough to warrant a separate application. In each case, a move in centrality away from the river was evident. The change from streetcars to buses only served to reinforce this pattern but did not significantly alter it until 1968. At this point a change in the pattern did appear. The linking of the north-south routes along Tecumseh Road, in the western portion of the city, together with considerable interstitial growth in both the eastern and western parts, caused a split in centrality (Map VIII-A). Places ranking as second appeared around Ouellette and Wyandotte in the north, and around Tecumseh and Ouellette in the south, separated by areas ranking as third and sixth in
Map VI-A

WINDSOR, 1937, STYLIZED
Map VIII-A
WINDSOR, 1968, STYLIZED
in between. However, it is interesting that beyond this area the bus lines are copying the early patterns and again branching out into radial lines, illustrating the growing importance of south Windsor. The split in centrality certainly seems to reinforce this observation. It also implies that the main core area of the thirties has greatly expanded, resulting in a new core which includes the entire area of the former City of Windsor (Map VIII).

Therefore, it may be concluded that the Windsor system did evolve from a 'high-cost-to-use' into a 'least-cost-to-use' situation. Improved connectivity did result when more efficient means of public transportation was adopted. Lastly, there were observable variations in connectivity produced by the evolving network.

This method of measuring centrality does have a certain amount of practical value. Nevertheless, its application could be restricted to use by the transit companies only, since centrality is computed in relation to the network. Thus the most central point in the network may not necessarily correspond with the most central point in the city. In addition, a person interested in obtaining land in the most central location may find land values too high. However, after employing this method he may find other areas of equal centrality away from the CBD, priced at a more desirable level. On the other hand, physical centrality today is not as important as accessibility and speed of travel. Therefore, a change in the time-distance relation-
ship, together with a more efficient form of public service could again alter the existing conditions and in time supplant the present central city.
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