71-18,335

YOUNG, Cyrus William, 1943-
TRANSPORTATION NETWORK DEVELOPMENT: THE RAILROAD NETWORK OF SOUTHERN MICHIGAN.

Michigan State University, Ph.D., 1970
Geography

University Microfilms, A XEROX Company, Ann Arbor, Michigan

TRANSPORTATION NETWORK DEVELOPMENT: THE RAILROAD NETWORK OF SOUTHERN MICHIGAN

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A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Geography

1970

ABSTRACT

TRANSPORTATION NETWORK DEVELOPMENT: THE
RAILROAD NETWORK OF SOUTHERN MICHIGAN

by Cyrus W. Young

This research conceives the transportation network as the product of a large number of individual link location decisions. Each decision maker is faced with a large number of potential link locations from which to choose; he orders these opportunities on the basis of their expected profitability and selects the best alternatives. The problem then becomes one of identifying regularities in the behavior of the individual decision makers.

It is possible to explain the development of the transportation network by deriving rules of behavior for the link location decisions. Given the opportunities available to the decision makers, the behavioral axioms specify the alternatives accepted and those rejected and thus reproduce the development of the network.

To derive the rules of behavior it is necessary to identify the characteristics of the potential links influencing the location decisions. The previous research on network location does not provide insights into the factors having an effect on the selection of link locations. To alleviate

this deficiency it is hypothesized that the decision makers are influenced by the amount of traffic which would be 1) generated by the two nodes connected by the potential link, 2) carried by the potential link from being part of a major inter-city route, and 3) carried by a potential link owing to its proximity to major urban centers. These three factors should affect both the decisions to expand the network as well as those to abandon parts of the network.

To identify the factors having the greatest impact on the location decisions, discriminant analysis is used. This analytic method, given the groups of alternatives accepted and rejected by decision makers, determines the characteristics of the alternatives which maximize the differences between the two groups. The discriminant analysis model thus forms the rule of behavior.

To test the three part conceptualization of the network growth process, the expansion of the railroad network of southern Michigan between 1860 and 1920 is used. During the first two decades, 1860 to 1880, the potential of the two nodes connected by the alternatives for generating traffic was the most important influence in the decision making process. The entrepreneurs preferred the link locations in areas with the smallest number and percentage of nodes served by competitive railroads. From 1880 to 1890 the proximity of alternatives to major inter-city routes had the greatest impact on location decisions. There was a tendency for the entrepreneurs to choose the potential links paralleling, but away from, the major inter-city lines. This behavior is an indication of the preference for locations isolated from established rail lines. No generalization could be made about the small amount of growth that took place between 1890 and 1910. From 1910 to 1920 propinquity to major urban-economic centers had the greatest impact on link location selection.

The decline of the railroad network of southern Michigan between 1910 and 1967 shows that proximity to the major inter-city paths was the most important factor in making abandonment decisions. Links adding the greatest distance to the inter-city routes, and to a lesser extent those farther from the routes, were more likely to be abandoned. Propinquity to major urban-economic centers, while being the most important factor in 1910, declined in significance in the decision making process until it had a negligible effect after 1952. The potential of a link for generating local traffic had a secondary impact on abandonment decisions.

The approach used in this research contributes to the further understanding of the network development process and indicates future avenues of investigation. Suggested improvements in the models include the incorporation of the locations of competitive links and routes, and the direction of growth.

ACKNOWLEDGMENTS

Many individuals gave their help through all stages of this research. I wish to express my appreciation to Dr. James Wheeler, my advisor, for his assistance during the preparation of this dissertation. I am indebted to Dr. Gerard Rushton, now of the University of Iowa, for his suggestions during the initial formulation of this research. Professor Lawrence Sommers deserves special thanks for helping me progress through my graduate studies.

My appreciation is extended to Dr. Charles Wrigley and the undergraduate programming staff of the Computer Institute for Social Science Research for their assistance. I am also grateful to Mrs. Carol Webb who patiently typed and retyped the manuscript.

Finally, I wish to thank my wife, Diane, for her encouragement and willingness to put up with my difficult moments.

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CHAPTER I

TRANSPORTATION NETWORK DEVELOPMENT:[1] AN INTRODUCTION AND REVIEW

The physical spread of the transportation network is an important spatial-temporal process; yet relatively little is known about it. In comparing the literature of transportation network development[2] with that of transportation network flows[3] and the impact of transportation network

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[1]For some basic definitions dealing with transportation networks used in this chapter and throughout the dissertation see Appendix I.

[2]William L. Garrison and Duane F. Marble, "The Structure of Transportation Networks," Transportation Center at Northwestern University, 1962; Edward J. Taaffe, Richard L. Morrill, and Peter R. Gould, "Transport Expansion in Underdeveloped Countries: A Comparative Analysis," The Geographical Review, LIII (October, 1963), 503-29; Karl J. Kansky, Structure of Transportation Networks: Relationships Between Network Geometry and Regional Characteristics, Department of Geography Research Paper No. 84, University of Chicago (Chicago: By the author, 1963), pp. 122-147; David E. Boyce, "The Generation of Synthetic Transportation Networks," Transportation Center at Northwestern University, 1963; William L. Garrison and Duane F. Marble, "A Prolegomenon to the Forecasting of Transportation Development," Research Report, Transportation Center at Northwestern University, Evanston, Illinois, 1964, pp. 97-108; William R. Black, "Growth of the Railway Network of Maine: A Multivariate Approach," Discussion Paper No. 5, Department of Geography, The University of Iowa, 1967; William R. Black, "An Iterative Model for Generating Transportation Networks," Miami University, n.d.; William R. Black, "The Generation of Transportation Networks: Their Growth and Structure" (unpublished Ph.D. dissertation, University of Iowa, Department of Geography, 1969).

[3]For example, see Edward L. Ullman, American Commodity Flows (Seattle: University of Washington Press,

change,[4] the latter two areas have a better developed body of literature, which has evolved over a longer period of time.[5] It is only within the last decade that network development has become a major research topic.

A partial explanation of this lack of emphasis on network change may lie in the attitude of the geographic profession, reflected in the following statement by Peter Haggett:[6]

1957); Peter R. Gould, The Development of the Transportation Pattern of Ghana (Northwestern University Press, 1960); Walter Isard, et al., "Interregional Flow Analysis," Methods of Regional Analysis: An Introduction to Regional Science (Cambridge, Massachusetts: The M.I.T. Press, 1960), pp. 122-181; Brian J. L. Berry, Essays on Commodity Flows and Spatial Structure of the Indian Economy, Department of Geography Research Paper No. 111, University of Chicago (Chicago: By the author, 1966); Peter R. Gould and Robert H. T. Smith, "Method of Commodity Flow Studies," The Australian Geographer, VIII (1961), 73-77.

[4]For example, see Rene Lachene, "Networks and the Location of Economic Activities," Papers, Regional Science Association, XIV (1964), 183-96; Allan Pred, The External Relations of Cities During "Industrial Revolution," Department of Geography Research Paper No. 76, University of Chicago (Chicago: By the author, 1962), pp. 29-43; Howard L. Gauthier, "Transportation and the Growth of the São Paulo Economy," Journal of Regional Science, VIII (1968), 77-94; Edgar M. Horwood, Carl A. Zellner, and Richard L. Ludwig, Community Consequence of Highway Improvements, National Cooperative Highway Program Report 18, Highway Research Board, National Academy of Sciences-National Research Council, 1965; William L. Garrison and Marion E. Marts, Geographic Impact of Highway Improvements (Seattle: Department of Geography and Department of Civil Engineering, University of Washington, 1958); William L. Garrison, et al., Studies of Highway Development and Geographic Change (Seattle: University of Washington Press, 1959).

[5]For a detailed review of much of this transportation literature see Peter Haggett and Richard Chorley, Network Analysis in Geography (New York: St. Martin's Press, 1969).

[6]Peter Haggett, "Network Models in Geography," Models in Geography, ed. by Richard J. Chorley and Peter Haggett (London: Methuen and Co., Ltd., 1967), pp. 610-11.

> The simplest component of the geographical network, the single line or path, would appear to pose few problems or provide much scope of worthwhile analysis. Yet, perhaps because of its fundamental character as the 'building block' of complex networks, both the location and the form of the single line are surprisingly difficult to explain.

This unexpected difficulty may result from the overly simplistic approach to the problem of network location; if any link of a network is examined independently of the remainder of the network, explanation of the location of that link becomes extremely difficult. The proper procedure is to determine within the context of the entire network whether or not a link should be constructed. A review of the literature will serve to emphasize the strengths and weaknesses of the methodology used by previous researchers.

Review of the Literature

The body of literature on transportation network development as mentioned above is relatively small. It may be divided into two parts: 1) static models of the network,[7] and 2) models of network change.[8] The static models unrealistically imply that historical inertia is an insignificant force in the location of human activities; therefore,

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[7] Garrison, "Structure of Transportation Networks"; Kansky, Structure of Transportation Networks, pp. 122-47; Boyce, "Synthetic Transportation Networks"; Garrison, "Forecasting of Transportation Development," pp. 97-108.

[8] Taaffe, "Transport Expansion"; Richard Morrill, Migration and the Spread of Urban Settlement, Lund Studies in Geography, Series B, Human Geography No. 26 (Lund, Sweden: C. W. Gleerup, 1965); Black, "Growth of the Railway Network"; Black, "Models for Generating Transportation Networks"; Black, "Generation of Transportation Networks."

these static models contribute little to this research and are not reviewed here.[9]

Models of Network Change[10]

In constructing a model of transportation network development in underdeveloped countries Taaffe, Morrill, and Gould viewed the expansion of the network "from its beginning at once to be a continuous process of spatial diffusion."[11] This study represents the first time that the development of the transportation network was explicitly conceived as a spatial-temporal process. The regularities underlying the spatial diffusion process permit a descriptive generalization, the "ideal-typical sequence."[12] While the

[9]For the reader who is not familiar with these models a brief review is found in Appendix V. For a more complete review see Haggett, Network Analysis.

[10]The review of the literature dealing with network change omits any studies which do not explicitly present generalized models of network development; for example, see James E. Vance, Jr., "The Oregon Trail and Union Pacific Railroad: A Contrast in Purpose," Annals, Association of American Geographers, LI (1961), 357-79; D. W. Meinig, "A Comparative Historical Geography of Two Railnets: Columbia Basin and South Australia," Annals, Association of American Geographers, LII (1962), 394-413; Andrew F. Burghardt, "The Origin and Development of the Road Network of the Niagara Peninsula, Ontario, 1770-1851," Annals, Association of American Geographers, LIX (1969), 417-40.

[11]Taaffe, "Transport Expansion," p. 504.

[12]The first stage of the sequence is penetration of transportation lines from ports, followed by the development of a feeder system around the interior nodes, and then interconnection of the interior nodes. The last stage of the process is the development of high priority "main streets" between the major centers. For a detailed discussion of the sequence, see Ibid., pp. 504-506.

model is helpful in understanding the changes that take place in the transportation network, it is only a descriptive generalization.[13] Therefore it does not allow prediction of the location of the links of a network or the changes that will take place over any period of time.

Morrill also identified transportation network change as an evolutionary process in his treatise on the growth of cities in Sweden.[14] He is the first researcher to introduce an elementary type of decision making. He developed a model for locating new transportation routes based on four stages.[15] While the model is an improvement

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[13]For an example of a test of this model, see Burghardt, "Road Network of the Niagara Peninsula."

[14]Morrill, Migration and Urban Settlement.

[15]The four stages are as follows:

> 1) The demand for new transportation routes may be given as outside economic data or be a function of development. . . . There is demand that area s be connected, if the urban population reaches a threshold level, and the cost of addition does not exceed some minimum. . . .
> 2) Each demanded link has several specific alternative routes. . . . The route must not be more than pi/2 longer than the shortest possible; i.e., must be contained in the circle, the diameter of which is the shortest route. . . .
> 3) To choose a particular route for a demanded link, it is necessary to determine the probability of the various alternatives. . . . The raw probability or 'attractiveness' of a route, is a function of the population of the area traversed, in which urban population has the greatest weight, the length of the routes, and the costs. . . .
> 4) A specific route is chosen by means of random numbers. . . . These probabilities may be taken to mean in this case the relative lobbying strength of the proponents of the three alternatives. Which group would prevail is uncertain.

(Ibid., pp. 88-89).

over the previous attempts to duplicate the transportation network, it has certain inherent weaknesses.[16] The major criticisms of the model are that it requires too much information to identify and evaluate the alternatives, and the rules for choosing the alternatives are not rigorously defined.

The conceptualization by Morrill of the developmental process appears to be backwards. The diffusion process as identified by Taaffe[17] had the network diffusing out from a point. The expansion was viewed as a movement from the origin and later from points on the network to nodes not connected to the network. Morrill takes a view counter to this. He makes an *a priori* decision as to the nodes to be connected, and then chooses the best route. This procedure is equivalent to saying the decision makers determine the best way to connect a center, instead of determining which is the best connection that can be made regardless of the centers connected.

Even though the conceptualization of the process is not completely correct, this model is an improvement over the previous research. Morrill's contributions are the emphasis he places on the time dimension and his identification of a potential set of alternative links from which to make a choice.

Black also explicitly identified "transport growth as a diffusion process whereby links are allocated through

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[16] The demand for new routes is determined in a large proportion of cases from outside information, and the remainder of the time through the assignment of arbitrary thresholds. Secondly, the value pi/2 is arbitrarily defined in determining the set of alternatives. Finally, calculating the probabilities urban population is arbitrarily weighted.

[17] Taaffe, "Transport Expansion."

time and over space."[18] He approaches the problem at a micro-level, in which emphasis is placed on "accounting for the location of new transportation linkages in any particular time interval." Black made a major improvement in conceptualizing the process when he conceived of the network existing at time _t_ as being a function of the characteristics of the nodes and the network at time _t-1_.[19] Black also considered the problem of identifying a set of potential links, from which the routes to be constructed would be selected. The identification of potential links also was a major conceptual improvement, but was unfortunately methodologically unsatisfactory.[20]

Black is the first researcher to introduce some elementary ideas concerning the behavior of individual decision makers in constructing the transportation network. This behavioralism is demonstrated by the following statement.[21]

> In the past research this threshold value [threshold population of nodes] has been chosen arbitrarily; here however, it will be the value which is evidently a minimum for generating sufficient traffic to warrant a link, as judged by the railroad entrepreneurs.

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[18]Black, "Growth of the Railway Network," p. 2.

[19]_Ibid._, pp. 1-2.

[20]Using the ideas of Boyce, potential connections were identified by Black for the nearest neighbor in six 60 degree sectors around each node. This meant that each node has a potential of up to but not more than six connections. While this may be methodologically satisfactory for Maine in 1840, it is not realistic for more urbanized areas. Black dropped this method in his later work.

[21]Black, "Growth of the Railway Network," pp. 3-4.

Regrettably this superfical reference to individual behavior was the only one he explicitly made. The hypotheses tested by Black were all non-behavioralistic.[22] If Black would have continued his behavioralistic viewpoint, he would have been able to refine and restate these hypotheses, and make some more meaningful generalizations.[23]

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[22]The seven hypotheses are as follows:

1) There is an inverse relationship between link construction and distance Dp from the point which the network began. . . .
2) There is an inverse relationship between link construction and link length. . . .
3) There is a positive relationship between link construction and link weight. (product of the population of the nodes) . . .
4) There is a positive relationship between link construction and potential interactance of the links involved. (P_iP_j/d_{ij}) . . .
5) There is an inverse relationship between link construction and the presence of an intervening opportunity in the interstitial nodal space. . . .
6) There is a positive relationship between link construction and the function $P_iP_j/d_{ij}/D_p$. . . .
7) There is an inverse relationship between link construction and deviation from the optimal direction that the minimum cost-maximum service network should take. [least squares line fitted to the set of potential nodes]

(_Ibid._, pp. 10-12).

[23]For example, the sixth hypothesis could have stated that the amount of interaction taking place along a link was a function of the distance to the major economic center; therefore, the distance from the potential link and the major economic center will influence location decisions. Similarly, the second, third, and fourth hypotheses could have been restated in the following form: a decision maker perceives the expected amount of locally generated interaction along a link as being directly related to the size of the end points and indirectly proportional to the length of the route.

Black, in a later attempt to improve the model discussed above,[24] recognized the problem in which a decision maker might choose to join two major urban centers by a series of links. He implicitly included this goal formation in his model by adding the cosine of the angle of the new link with the existing network as a variable. But unfortunately the algorithm used in the model could only be applied to simple networks which have no loops,[25] that is, networks that have not started the process of interconnection. Also the tests of the revised model were not conclusive; therefore, at the present time the model can not be judged a success.

Statement of the Problem

The investigation by Morrill contained several contributions, but unlike the work of Black it does not provide an avenue for further inquiry. Many new innovations can be found in Black's research; however, he did not explicitly try to duplicate the entrepreneural location decisions. Instead he made a dichotomous classification of potential link locations. Therefore he could make very few meaningful generalizations.

The network should be conceived as the product of a large number of individual location decisions. At any

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[24]Black, "Model for Generating Transportation Networks"; Black, "Generation of Transportation Networks."

[25]Such a network is technically referred to as a "tree," which by definition contains no "circuits" (loops).

point in time a decision maker is faced with a number of alternative locations on which to construct links of the network. These opportunities are evaluated based on their characteristics, and the location or set of locations with the greatest anticipated utility is chosen. The problem then becomes one of identifying regularities in the behavior of individual decision makers.

It is possible to explain the development of the transportation network by deriving a set of rules of behavior for the individual decision makers. These behavioral postulates do not directly specify the form and development of the network, but they make feasible the duplication of the individual decisions.[26] From these decisions it is possible to reproduce the development of the transportation network.

The purpose of this research is to derive a set of meaningful rules of behavior for the railroad entrepreneurs in southern Michigan. This type of an approach to the problem of network development yields more meaningful generalizations than those produced in the past research; and it provides a foundation for refinement and restatement of the behavioral postulates by identifying avenues for future research.

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[26]This is not meant to imply that the actual decision making process as it was performed by each individual will be duplicated. It will only be possible to establish from the characteristics of the alternatives a set of rules which will permit the reproduction of the decisions. The rules will not represent the duplication of actual decisions.

Overview of the Research

To attain this purpose it is necessary to identify the factors which influence the location decisions by the entrepreneurs. The previous work on network location does not provide much insight into the factors influencing link location choices. To alleviate this deficiency a three part conceptualization of network evolution as a spatial decision making process is hypothesized (Chapter II). The hypotheses may be briefly stated as follows:

1) the amount of interaction which would be generated by the two nodes connected by a potential link of the transportation network influenced the location decisions;
2) the amount of interaction which would be carried by a potential link due to proximity to major urban centers influenced the location decisions;
3) the amount of interaction which would be carried by a potential link from being part of a major intercity route influenced location decisions.

Chapter III provides a description of the discriminant analysis methodology that is used to test the models and a summary of the variables used in the models. Two sets of models are constructed to test the hypothesized concepts and to derive a set of rules of behavior; one set for the growth (Chapter V) and another for decline (Chapter VI) of the railroad network of southern Michigan. A brief history of the railroad network of southern Michigan precedes the analyses (Chapter IV), and a summary and conclusions follow the analyses (Chapter VII).

CHAPTER II

CONCEPTUALIZING TRANSPORTATION NETWORK DEVELOPMENT: A SPATIAL DECISION MAKING PROCESS

The relatively limited success of most of the network growth models may be owing to the fact that the process of transportation network development lacks any complete conceptualization in the literature. Three concepts are evolved in this chapter; they are intended to form the basis for the models which are derived in Chapters V and VI. These suppositions are treated as hypotheses since their relative significance in the actual link location decision making process is determined within the models.

Transportation Network Growth

The location of each link of the railroad network represents the result of a decision by an entrepreneur.[1] In making each individual decision the entrepreneur is faced with a set of alternative locations on which to construct a link of the network. Each location has an anticipated relative value, that is, expected utility, to the decision

[1]This discussion is in terms of entrepreneural decisions in the development of the railroad network; but it could have been in the context of public development of the highway network, in which case the decision makers would have been highway planners.

maker based on its characteristics.[2] The entrepreneur orders the alternatives as to their utility, and chooses the opportunity which is maximum.

The value of a location for an entrepreneur constructing a railroad could simply be defined as the expected profit from the operation of a link at that location. The entrepreneur assesses from the characteristics of the potential link the expected level of return. The identification of the attributes, which are used by the entrepreneurs in making their location decisions, is a necessary prerequisite for deriving any behavioral postulates. These rules permit the duplication of the decision making process which produced the past and present transportation networks.

Local Interaction

The length of a link and the size of the nodes which it connects are the most directly obvious and measurable characteristics of a link which will influence location decisions. Knowing these attributes the entrepreneur should be able to make some estimate of the amount of locally generated interaction which will take place as a result of the two nodes being connected by the link. These two attributes could be used as surrogates for the potential amount of revenue, while the costs of construction and operation could be assessed from the length of the link. In addition to the population of

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[2]This is expected utility since the decision maker does not have perfect knowledge.

the nodes, the size of the hinterland of each of the nodes should also be an important influence on the location decisions. If there were no urban centers which were connected to the network proximal to a location of an alternative, the potential link would have a greater likelihood of being constructed.

An entrepreneur should perceive a potential link connecting two major centers which have large hinterlands as being likely more profitable than one connecting two minor centers that have smaller service areas; likewide the longer a link is, the less profitable it would be. Thus there should be a trade-off between the size and hinterland of the nodes and the length of the link. The precise nature of this relationship can only be determined through the construction of a preference function. With such a function it would be possible to see how the decision makers ordered their alternatives and made their location choices. Unfortunately the situation is not quite this simple, for there are attributes of the links other than the surrogates for locally generated traffic which influence location decisions.

Path Effect

In considering local interaction the decision maker's perception of alternative locations for links is conceived as being independent of the characteristics and locations of the other links or potential links of the network. It is likely that the entrepreneurs might conceive of his set of alternatives on a larger scale, in which case he would view his set of opportunities as being groups of links which would be used to join two major urban-economic centers. Thus similar to the previous situation dealing with the anticipated amount of locally generated interaction between two nodes, the entrepreneur should envision some level of traffic flow between two larger nodes connected by a series of links. The larger the major centers, the greater should be the amount of traffic carried by the route, and the longer the distance separating the two centers, the smaller the amount of traffic.

The problem then is to identify the set of centers the decision makers consider to be opportunities to be connected. Black has referred to this phenomenon as goal formation by the entrepreneurs.[3] But there is still other information which is relevant to the decision making problem. Once an entrepreneur decides that he is going to construct a route between two major centers, he must choose the path this route should take, that is, the set of intermediate nodes that should be connected. The decision maker must choose between building the shortest possible route between the two major nodes and lengthening the path to include smaller intermediate nodes. A preference function could be hypothesized to show the trade-off of increased length of the route necessary to connect intermediate nodes and the size of

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[3]Black, "Model for Generating Transportation Networks"; Black, "Generation of Transportation Networks."

the nodes. But such a function would be very difficult to construct since there are a very large number of potential alternative groups of links, with only a few intermediate nodes.[4] The determination of the alternatives even for a small number of paths would be a major problem.

This dilemma has been identified as "Wellington's Problem,"[5] and is referred to as the path effect in this research. Scott has identified a linear programming formulation which provides an optimal solution to this problem,[6] but unfortunately this formulation is so complicated that there is no algorithm for its solution. But even if there were a solution, it would not satisfactorily describe the actual process, since the entrepreneur does not have perfect knowledge. He evaluates the alternatives he perceives with his available information, which is far from complete, and chooses the opportunities which maximize the expected utility.

The problem of conceptualizing the path effect does not have any simple solution as in the situation involving local interaction in which it is possible to envision the existence of a simple preference structure. With the path

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[4]The total number of possible alternatives would be $\sum_{i=1}^{n+1} i!$, where n is the number of intermediate nodes.

[5]For a discussion of this problem, see Haggett, Location Analysis, p. 62.

[6]Allen Scott, "A Programming Model of Integrated Transportation Networks," Papers, Regional Science Association, XIX (1967), 215-22; Allen Scott, "An Integer Program for the Optimization of a System of Chromatic Graphs," Journal of Regional Science, VII, Supplement (1967), 291-96.

effect the entrepreneur is faced with a complex situation in making each location decision, because the location for each path has so many contingencies. Thus to construct an operational model, which is done in the next chapter, it is necessary to simplify the actual process.

Field Effect

A third factor which should have an effect on entrepreneural location decisions is proximity to major urban-economic centers. This attribute is related to the phenomenon which is generally referred to as the "field effect" of a major urban center. The closer a link is to a major economic center, which is a focal point of interaction, the greater should be the probability that the link would handle traffic generated externally from the two nodes directly connected by the link. Thus, for example, a potential link that is relatively long and connects two comparatively small nodes would not be very attractive to an entrepreneur from the point of view of locally generated interaction; but the alternative still might be constructed if it happened to form part of a path between several larger economic centers.

A decision maker should evaluate the potential of the link for diverting traffic from other routes to the path containing the link, as well as generating new traffic. This type of motivation should be particularly important in the interconnection stage of development.[7]

Transportation Network Decline

Whereas there has been much emphasis placed on the growth of networks in the literature, the decline of networks has been virtually ignored. This neglect is particularly unusual considering the reduction in the spatial extent of the American railroad network.[8] This decline is the result of the growth of competitive modes of transportation, or in some areas the decline in the economies based on the exploitation of natural resources. It would, therefore, seem relevant in the present context to examine the process by which links are removed from the railroad network.

The process of network decline can be conceived as the physical and conceptual opposite of network growth. The entrepreneurs evaluate the utility of each of the links of the network and abandon the least profitable links; that is, the links generating the smallest amount of local traffic, and the links least important in forming paths between the major urban-economic centers and part of nodal systems.

Summary

In making location decisions entrepreneurs are influenced by three factors: 1) the amount of traffic generated by the two nodes connected by the alternative (local

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[7]See the discussion of the descriptive model of Taaffe, Morrill, and Gould in Chapter I (Taaffe, "Transport Expansion").

[8]For example, in southern Michigan over 1400 miles of the network have been abandoned since 1900.

interaction), 2) the distance from potential link to the nearest major inter-city path (path effect), and 3) the distance from alternative to the nearest major urban center (field effect). These three factors influence decision makers regardless of whether they are building or abandoning segments of the network, because transportation network growth and decline are conceptually the same. The only difference between the two aspects of the network development process lies in the entrepreneur choosing the best alternative with the growth of the network, and rejecting the worst alternative with the decline of the network.

CHAPTER III

DEVELOPMENT OF NETWORK CHANGE MODELS

The purpose of this research is to produce greater understanding of the network development process through the derivation of a set of rules of behavior and reproduction of the transportation network. To attain this purpose the models constructed must identify the attributes of the potential links which most strongly influenced location decisions; that is, they must specify the relative importance of each of the three concepts identified in the last chapter. The discriminant analysis model satisfies the above criterion.[1]

Discriminant Analysis Model

If the links accepted as alternatives[2] by the entrepreneurs are placed in one group and the potential links rejected are placed in a second group, then the discriminant analysis model identifies the combination of the attributes of the alternatives which maximizes the difference between

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[1]For a critical comparison of discriminant analysis and non-metric scaling, a possible alternative method of analysis, see Appendix III.

[2]The procedure for identifying the set of alternatives available to the entrepreneurs in making their location decisions is described in Appendix II.

the two groups.[3] This linear combination of the attributes is called a normalized discriminant vector or a discriminant function.[4] By standardizing the coefficients of the discriminant function,[5] it is possible to derive a new scaled discriminant function on which the size of the coefficients reflects the importance of each of the variables in distinguishing between the groups of alternatives. Thus it is possible to determine the relative significance of the three concepts identified in Chapter II. While discriminant analysis derives a weighting of the original variables which maximizes the differentiation between the two groups, it does not provide any information on how well the discrimination is between the two groups.

Test of the Model

It is possible to determine how well the model (the rules of behavior) predicts the alternatives accepted and rejected by calculating the discriminant scores for each alternative.[6] The discriminant scores of each of the alternatives

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[3]The attributes are defined for the alternatives at the beginning of each time period, since it is assumed that the entrepreneurs' judgment as to the future profitability of a potential link is based on the characteristics of the alternative before construction.

[4]For the mathematical derivation of the discriminant function see Appendix IV.

[5]This is done by multiplying the coefficients of the discriminant function by the within-group standard deviation.

[6]Geometrically this would be the projection of the original observations in the multi-dimensional attribute space on the discriminant vector.

are compared with the scores of the means of the groups. Using these deviations it is possible to calculate the likelihood of membership in each of the groups.[7] The links are then assigned to the most probable group. The percentage of misclassifications is a simple test of the model.

It is possible to reproduce the location decisions of the entrepreneurs and reconstruct the network using the discriminant analysis model. This type of model is only as good as the information with which it is provided; therefore the success of the behavioral postulates in depicting the real world relationships is dependent on the proper selection of variables.

Attributes of the Alternatives

Network Growth

Three concepts were developed in Chapter II to explain the growth of the network. A group of variables is identified for each concept. These hypothesized sets of attributes are presented in Table 1.

The variables in the first group, surrogates for local interaction, are the directly observable characteristics of a link, its length and the population and relative size of

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[7]A brief description of the decision rules is given in Appendix IV. For a more complete discussion see William W. Cooley and Paul R. Lohnes, Multivariate Procedures for the Behavioral Sciences (John Wiley and Sons, Inc., 1962), pp. 134-150.

TABLE 1.--Attributes of the alternatives

Variable Number	Variable Name
	Group 1--Local Interaction
1.	Length of the alternative
2.	Population of the larger node
3.	Population of the smaller node
4.	Number of urban centers connected to the network within ten miles of the alternative
5.	Percentage of urban centers connected to the network within ten miles of the alternative
6.	Number of urban centers connected to the network within twenty miles of the alternative
7.	Percentage of urban centers connected to the network within twenty miles of the alternative
8.	Number of urban centers connected to the network within thirty miles of the alternative
9.	Percentage of urban centers connected to the network within thirty miles of the alternative
	Group 2--Field Effect
10.	Number of connections to the smaller node
11.	Number of connections to the larger node
12.	Distance to the nearest major urban-economic center
13.	Distance to the second nearest major urban-economic center
	Group 3--Path Effect
14.	Distance added to the nearest least cost path by the connection of the node closer to the path
15.	Distance added to the nearest least cost path by the alternative given the initial connection of the node closer to the path
16.	Distance added to the nearest least cost path by the alternative given the initial connection of the node farther from the path
17.	Population of the node closer to the path
18.	Population of the node farther from the path
	Group 4
19.	Existence of Land Grants
20.	Distance to the nearest urban center connected to the network

the hinterland of the nodes directly connected by the alternative. Identification of these variables is relatively straightforward in comparison to the other two conceptual parts of the process. The only problem is determining the size of the hinterlands of the nodes. This size is resolved implicitly by identifying the number and percentage of competitive nodes within ten, twenty, and thirty miles of the alternative.

The variables in the second set are the surrogates for the field effect. The distances to the two nearest major urban-economic centers are the two most easily conceived surrogates. The major urban centers are delimited using an iterative procedure discussed below. The two remaining variables, the number of connections to the two nodes, are included since distance alone is not important if the links have a potential for carrying externally generated traffic. If each of the nodes connected by the link has only one other connection, then there is not as great a chance of diverting traffic from other routes.

The path effect is a highly complicated concept. As alternatives the entrepreneur identifies groups of links which form paths between major urban-economic centers. The length of the routes and the total size of the nodes connected are the attributes of these alternatives. However, this is methodologically unsatisfactory, for the models as they are developed here focus on the individual links.[8]

The five variables hypothesized for the path effect are more implicit than explicit. The first is the deviation of the alternative from the nearest least cost path (straight line) joining two major urban-economic centers. This deviation is measured as the distance added to the nearest least cost path by the connection of the node closer to the path. In Figure 1 this distance is $\overline{AC} + \overline{CB} - \overline{AB}$. The second variable is the distance added to the nearest least cost path by the alternative given the connection of the node closer to the path. In Figure 1 this distance is $\overline{CD} + \overline{DB} - \overline{CB}$; it is assumed with this variable that the movement is from major center A to major center B. The third variable, the distance added to the nearest least cost path by the alternative given the initial connection of the node farther from the path, is included to account for growth in the other direction; referring to Figure 1, it is $\overline{DC} + \overline{CA} - \overline{DA}$. The fourth and fifth variables of this group are the size of the node closer to the path and the size of the node farther from the path. In Figure 1 these variables would be the population of nodes C and D respectively.

The last four variables are included to depict a trade-off between the size of the intermediate nodes and

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[8]In addition, as was discussed above, the computional and conceptual complexity is too great for the problem to be approached from this viewpoint in this research; the delineation of the group of alternatives is a research topic in itself.

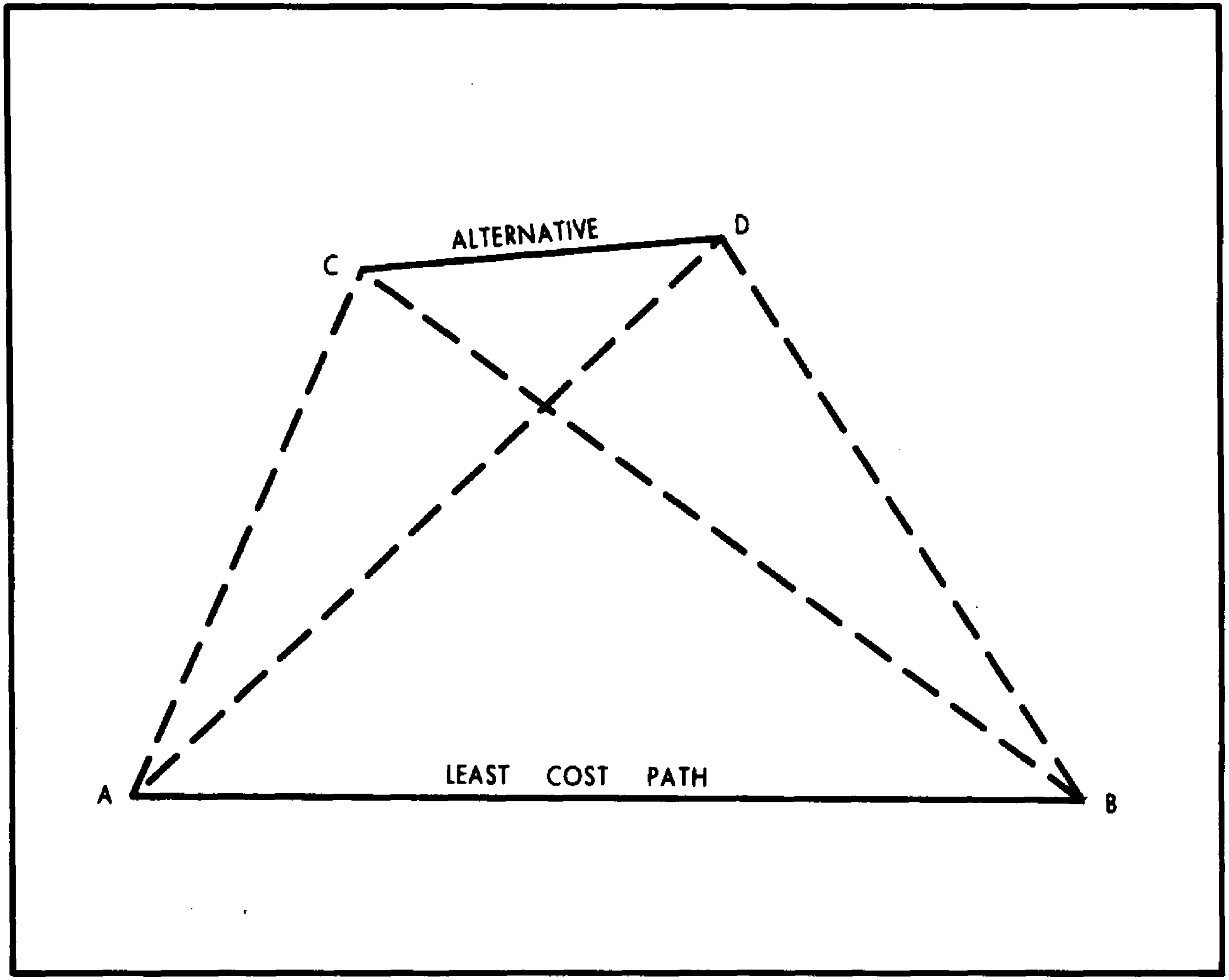

FIGURE 1.--Definition of path effect variables

the additional cost of lengthening the route, while the first variable should indicate the preference of the decision makers for links which cause a minimum deviation from the least cost route. All five of these variables are defined such that each link is considered independently of all other links. Using these variables produces greater generality in the model, but at the same time also leads to larger degrees of abstraction from reality.

The identification of the major urban-economic centers and the set of least cost paths joining them is a significant problem in operationally defining the last two groups of variables. It entails the delimitation of a population threshold which is necessary for an entrepreneur to perceive a city as an alternative in his goal formation. The threshold is determined by an iterative procedure. The distances to the nearest urban-economic centers and the set of least cost lines are determined for progressively larger groups of cities, where each successive group of cities has a lower population threshold.[9] Assuming the two sets of variables defined above are significant, the one group of cities which most closely approximates the size of the nodes perceived by the entrepreneurs produces the greatest contribution by the two sets of variables to the discrimination between the two groups of alternatives.

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[9]These variables will be calculated five times using the ten, twenty, thirty, forty, and fifty largest cities in the study area.

Two additional variables (Group 4, Table 1) are incorporated into the analyses. The first is supposed to take into consideration the impact of land grants on location decisions in the study area. This variable will be identified more completely in the analyses. The second variable is included to take into account the temporal aspects of the network development; it is the distance from the location of the alternative to the nearest urban center connected to the network at the beginning of the period. This variable should play a significant role in indicating variations in the expected utility of a link as the network diffuses through space.

In dealing with these four groups of variables it should be kept in mind that each of the groups is not completely independent of the other three. Because of this intercorrelation, it is only possible to determine the relative importance of the three hypothesized concepts in the decision making process.

Network Decline

The same group of variables used for network growth are employed in the model of network decline with two exceptions: the distance to the nearest node connected to the network and the land grant indicator are omitted since they are of course meaningless in this situation. The same variables are utilized because the two processes are similar in the sense that profit maximization is still the goal of the entrepreneurs. However, instead of constructing the most profitable links, the least profitable are abandoned.

Summary

Discriminant analysis is used to construct two sets of models (rules of behavior), one for network growth and the other for network decline. The attributes of the alternatives at the beginning of the time periods are assumed to influence the location decisions by the entrepreneurs. The method of analysis determines the importance of each of the variables in distinguishing between the two groups of alternatives. It is, therefore, possible to determine the relative significance of the three concepts hypothesized in Chapter II. The models are testable to determine how well they fit the real world.

CHAPTER IV

THE RAILROAD NETWORK OF SOUTHERN MICHIGAN

Southern Michigan

The lower peninsula of Michigan is chosen as the area in which to test the models developed in the previous chapters. There are several reasons for this choice. First, information on the area is readily available; second, the author is familiar with the area; and third, the Great Lakes act as a barrier to interaction on three sides of the area, reducing the problems of dealing with interaction with points outside the area. Southern Michigan is also of a different character than areas used in the other studies. With the exception of Black's use of Minnesota to test his model calibrated in Maine,[1] all of the previous research dealt with areas having established settlement patterns.[2]

Period of Study: 1860-1967

Although the first railroad development in Michigan started in 1838, 1860 is chosen as the beginning date of this

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[1]Black, "Generation of Transportation Networks."

[2]Garrison, "Structure of Transportation Networks"; Garrison, "Forecasting of Transportation Development"; Kansky, Structure of Transportation Networks; Boyce, "Synthetic Transportation Networks"; Black, "Growth of the Railway Network."

research because of the lack of population data for the nodes of the network, most urban centers being incorporated after the 1850 census. The omission of the 1838-1860 period is not significant, for the mileage of the track laid prior to 1860 is less than five percent of the total mileage eventually constructed.

Sources of Information

Three basic sources were used in compiling the information on changes in the railroad network. For the period prior to 1880 a list of dates of openings compiled by the Michigan Railroad Commission was used.[3] Maps published by the State of Michigan were used to locate modifications in the network from 1880 through 1930.[4] After 1930 the _Rand McNally Handy Railroad Atlas_ was used to compile all changes in the network.[5] These sources were supplemented by an exhaustive list of all openings, abandonments, incorporations, and mergers by railroad companies in Michigan.[6]

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[3]Michigan, Railroad Commission, _Fourth Annual Report of the Commissioner of Railroads of the State of Michigan for the Year Ending December 31, 1875_ (Lansing, Michigan: W. S. George and Co., 1876), pp. xxi-xxvii.

[4]Michigan, Secretary of State, _Michigan Official Directory and Legislative Manual_ (Lansing, Michigan, 1881, 1892, 1902, 1912, 1922, 1932).

[5]_Rand McNally Handy Railroad Atlas_ (Chicago: Rand McNally and Co., 1942, 1952, 1967).

[6]Michigan, Railroad Commission, _Outline of Development and Succession in Titles to Railroads in Michigan_ (Lansing, Michigan: Wynkoff Hallenbeck Crawford Co., 1919).

Population Statistics for the nodes of the network were taken from the United States Census.[7]

A Brief History of the Railroad Network of Southern Michigan

Three distinct periods can be identified in the evolution of the railroad network of southern Michigan. The first period from 1860 to 1890 was marked by the exclusive expansion of the network. The succeeding period, 1890 to 1920, was one of both network growth and decline. There was expansion in some areas, while links were abandoned in other sections of the network. The decline of the network completely dominated the third period from 1920 to 1967.

The Early Period: 1860-1890

By 1860 (see Map 1)[8] three major east-west lines crossed the state. All of the existing major urban centers were connected to the railroad network. The southern half of the study area had been penetrated by the railroad. During the decade from 1860 to 1870 (see Map 2), the network experienced the third largest addition of mileage; 775 miles were added to the network (see Table 2). Interconnections were

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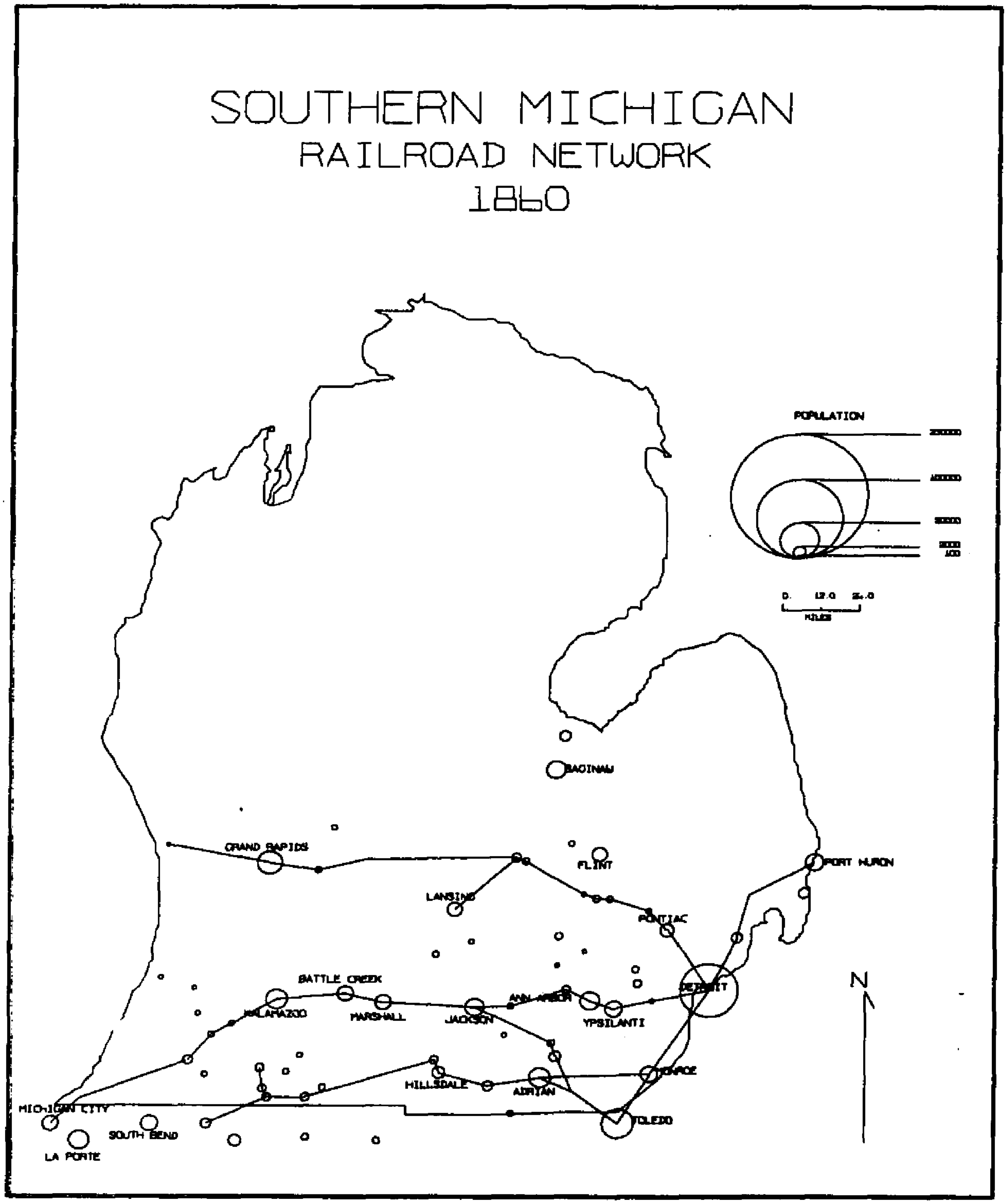
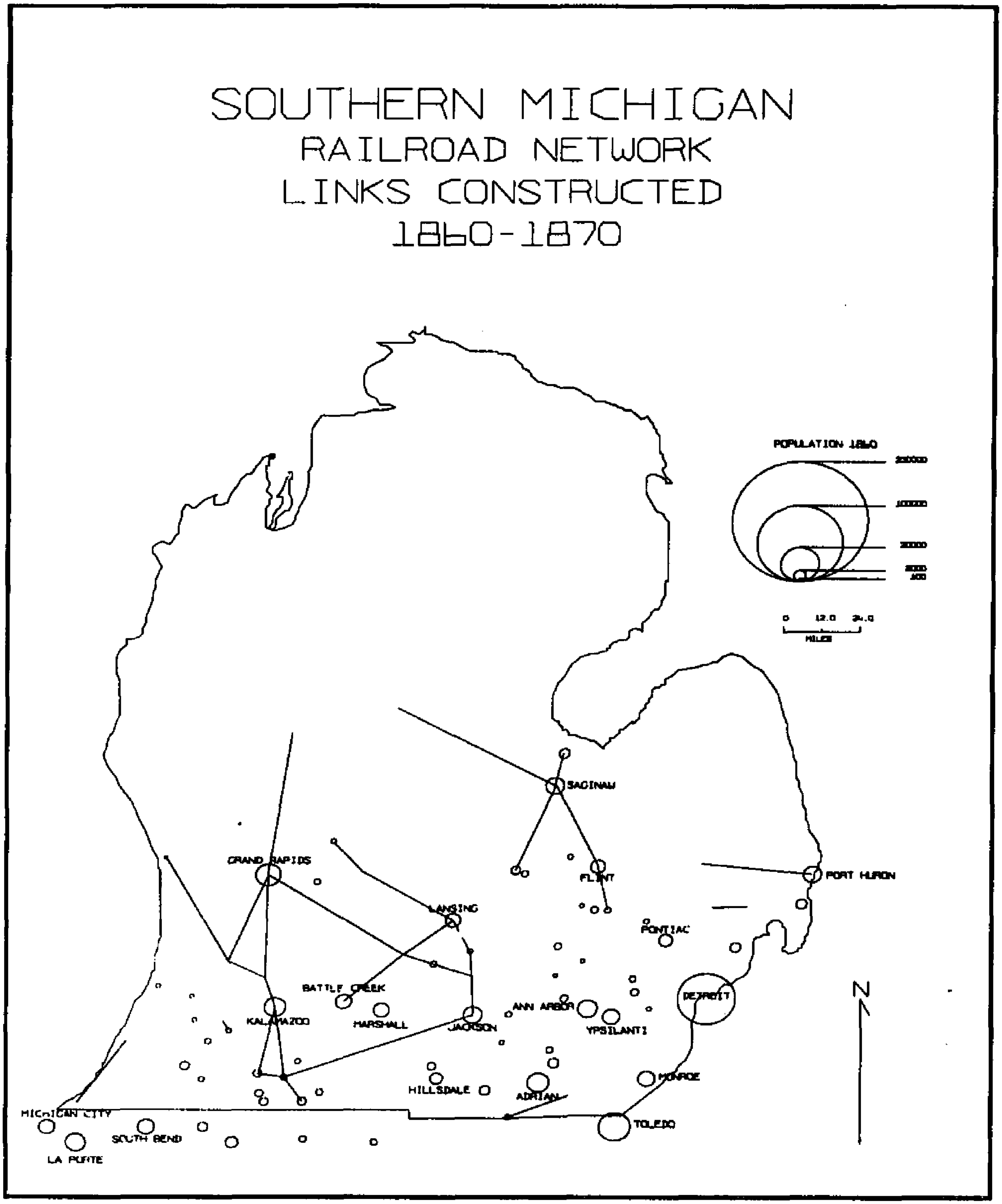
[7] U. S., Department of Commerce, Bureau of the Census, _Census of the United States, 1860, 1870, 1880, 1890, 1900, 1910, 1920, 1930, 1940, 1950: Population_.

[8] The maps in this dissertation were produced using Program MAPIT on a Calcomp Plotter in conjunction with a C.D.C. 3600 computer at the Computer Center, Michigan State University. To construct the maps it was necessary to supply the population and coordinates of the nodes, the nodes connected by each link, the coordinates of the outline, the title


SOUTHERN MICHIGAN
RAILROAD NETWORK
1860
POPULATION
SAGINAW
GRAND RAPIDS
FLINT
LANSING
PONTIAC
PORT HURON
BATTLE CREEK
KALAMAZOO
MARSHALL
JACKSON
ANN ARBOR
YPSILANTI
DETROIT
HILLSDALE
ADRIAN
MONROE
TOLEDO
MICHIGAN CITY
SOUTH BEND
LA PORTE
N

MAP 1


SOUTHERN MICHIGAN
RAILROAD NETWORK
LINKS CONSTRUCTED
1860-1870
POPULATION 1860
MILES
N
SAGINAW
GRAND RAPIDS
FLINT
PORT HURON
LANSING
PONTIAC
BATTLE CREEK
DETROIT
KALAMAZOO
MARSHALL
JACKSON
ANN ARBOR
YPSILANTI
MONROE
HILLSDALE
ADRIAN
TOLEDO
MICHIGAN CITY
SOUTH BEND
LA PORTE

MAP 2

made between the established lines, particularly in the southwestern and central portions of the state. There was a notable absence of expansion of the network in the area around Detroit during this ten year period. A second and equally prominent trend during this period was the beginning of the penetration of the network into the northern part of the state. A northward extension was begun from Grand Rapids eventually reaching Traverse City and Mackinaw City, in 1880 and 1890 respectively. One of the great goals during this first thirty year period was to connect Mackinaw City with the southern portion of the state.

TABLE 2.--Change in the railroad mileage of southern Michigan

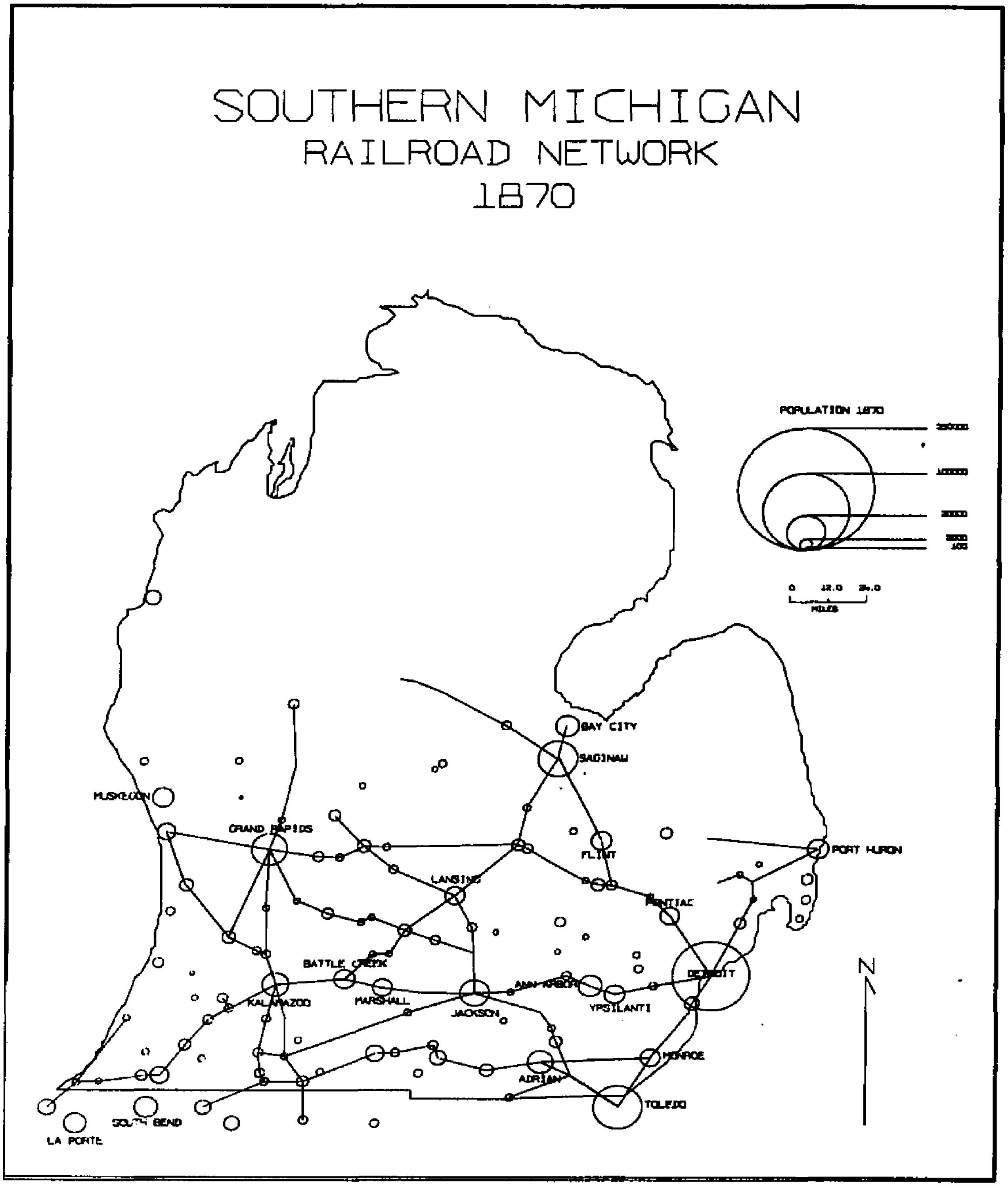
Year	Growth	Decline	Net Change
1860-1870	776	---	776
1870-1880	1764	---	1764
1880-1890	1750	---	1750
1890-1900	322	51	271
1900-1910	417	95	322
1910-1920	207	183	24
1920-1930	---	258	-258
1930-1942	---	380	-380
1942-1952	---	316	-316
1952-1967	---	196	-196

and labels with coordinates, and the size of the map. For a more complete discussion of Program MAPIT, see Robert Kern and Gerard Rushton, "Mapit: A Computer Program for Producing Flow Maps, Dot Maps, and Graduated Symbol Maps." Research Report, Computer Institute for Social Science Research, Michigan State University, East Lansing, Michigan, April, 1969; Robert Kern, "MAPIT: Map Drawing on the Calcomp Plotter, Technical Report No. 87, Computer Institute for Social Science Research, Michigan State University, East Lansing, Michigan, 1969.

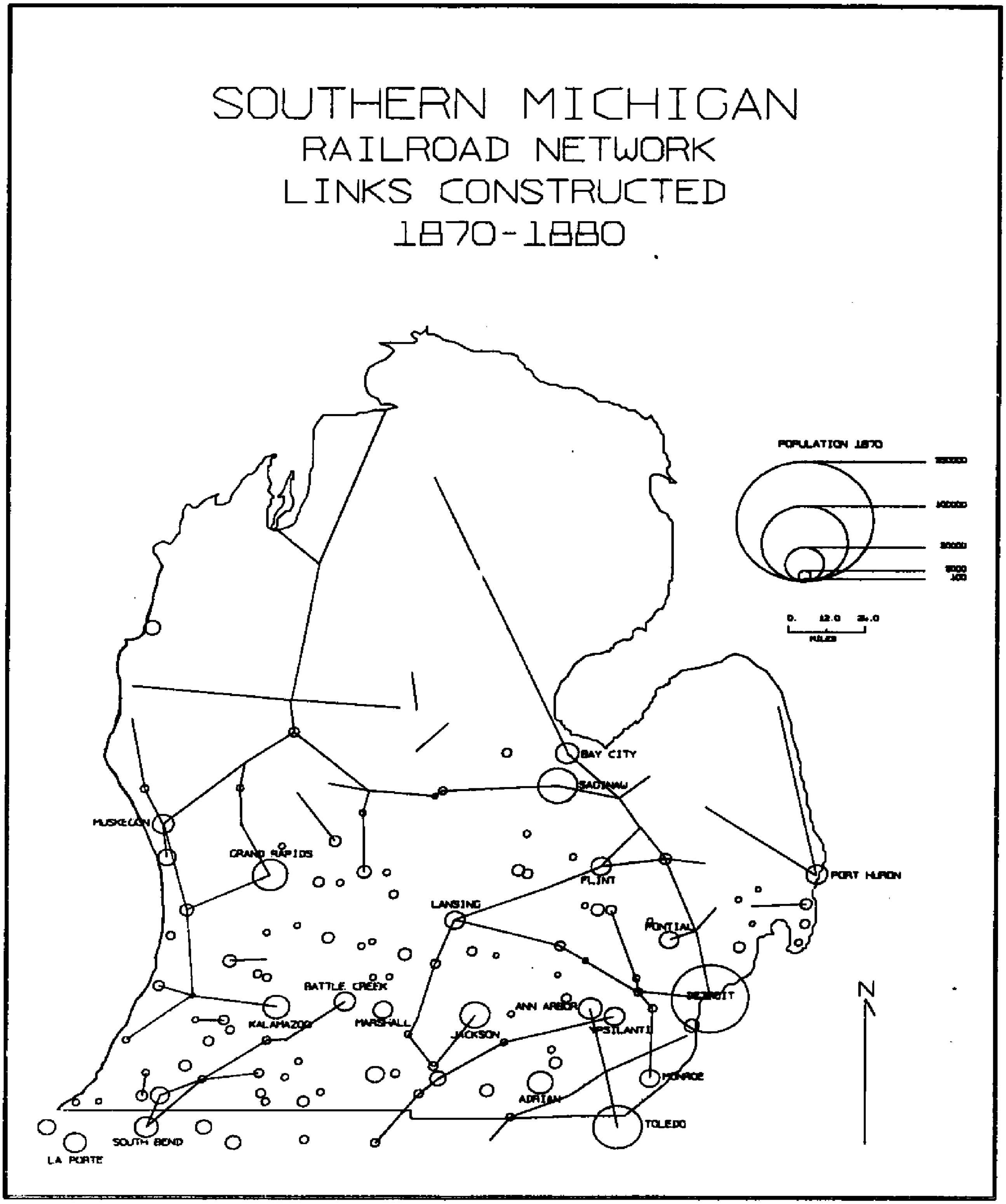
The development of the network up to 1870 formed the foundation for the future development of the network. Over 95 percent of the links of the network in 1870 were part of the network in 1967.

Between 1870 and 1880 (see Maps 3, 4, and 5) there was a continued filling in of the network in the southern portion of the study area, much of this development being concentrated in the southeastern quarter of the state. There was also continued penetration of the network into the northern portion of the state.

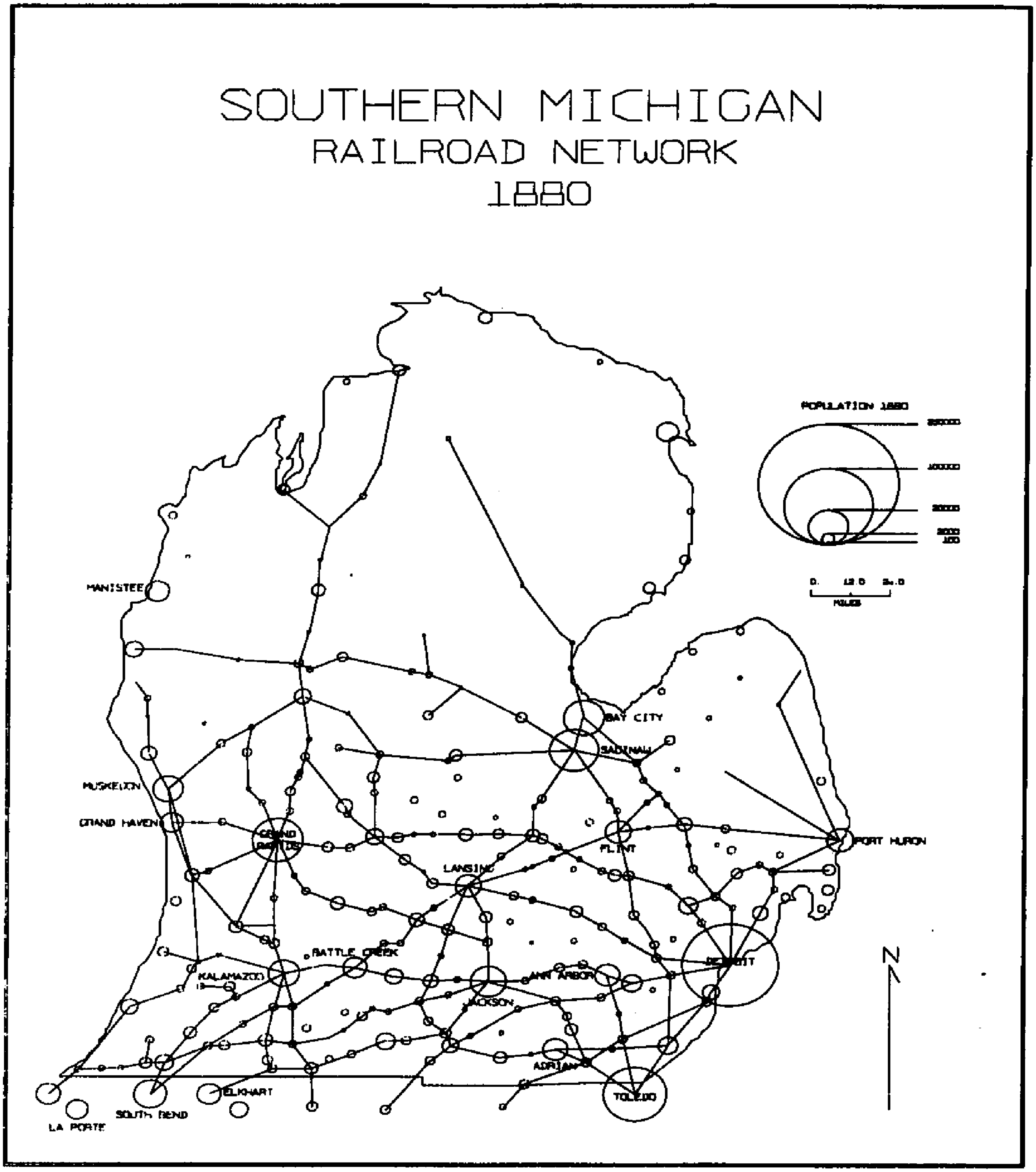
Up to 1880 only a small proportion of the expansion of the network took place in the area north of Bay City. However, growth occurred in the north between 1880 and 1890 (see Maps 5, 6, and 7). During this ten year period when 1750 miles were added to the network, there was a significant amount of expansion in the area north of Bay City. Approximately forty percent of the links added to the network were in this area. Mackinaw City was finally connected by two lines which had been supported by land grants, another route was being extended along the coast of Lake Huron, and there was an extensive amount of interconnection which had taken place in the area immediately south of Traverse City. Much of this growth was stimulated by the rise of the lumbering industry. In addition to the lines shown on the maps (see Map 6), there were many spurs and branch lines built off


SOUTHERN MICHIGAN
RAILROAD NETWORK
1870
POPULATION 1870
MILES
N
BAY CITY
SAGINAW
MUSKEGON
GRAND RAPIDS
FLINT
PORT HURON
LANSING
PONTIAC
BATTLE CREEK
DETROIT
KALAMAZOO
MARSHALL
JACKSON
ANN ARBOR
YPSILANTI
MONROE
ADRIAN
TOLEDO
SOUTH BEND
LA PORTE

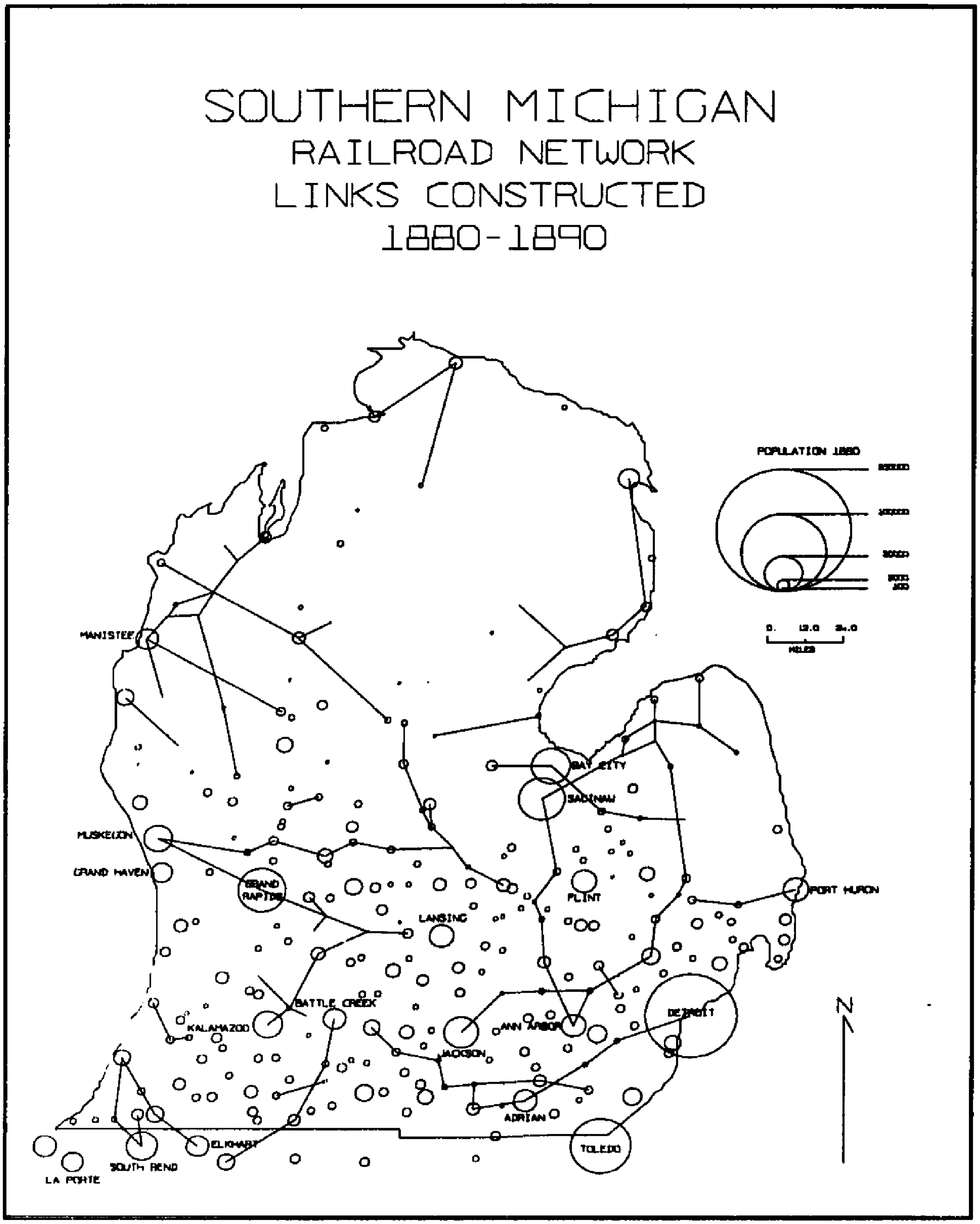
MAP 3


SOUTHERN MICHIGAN
RAILROAD NETWORK
LINKS CONSTRUCTED
1870-1880
POPULATION 1870
BAY CITY
SAGINAW
MUSKEGON
GRAND RAPIDS
FLINT
PORT HURON
LANSING
PONTIAC
BATTLE CREEK
KALAMAZOO
MARSHALL
JACKSON
ANN ARBOR
DETROIT
YPSILANTI
MONROE
ADRIAN
TOLEDO
SOUTH BEND
LA PORTE
N

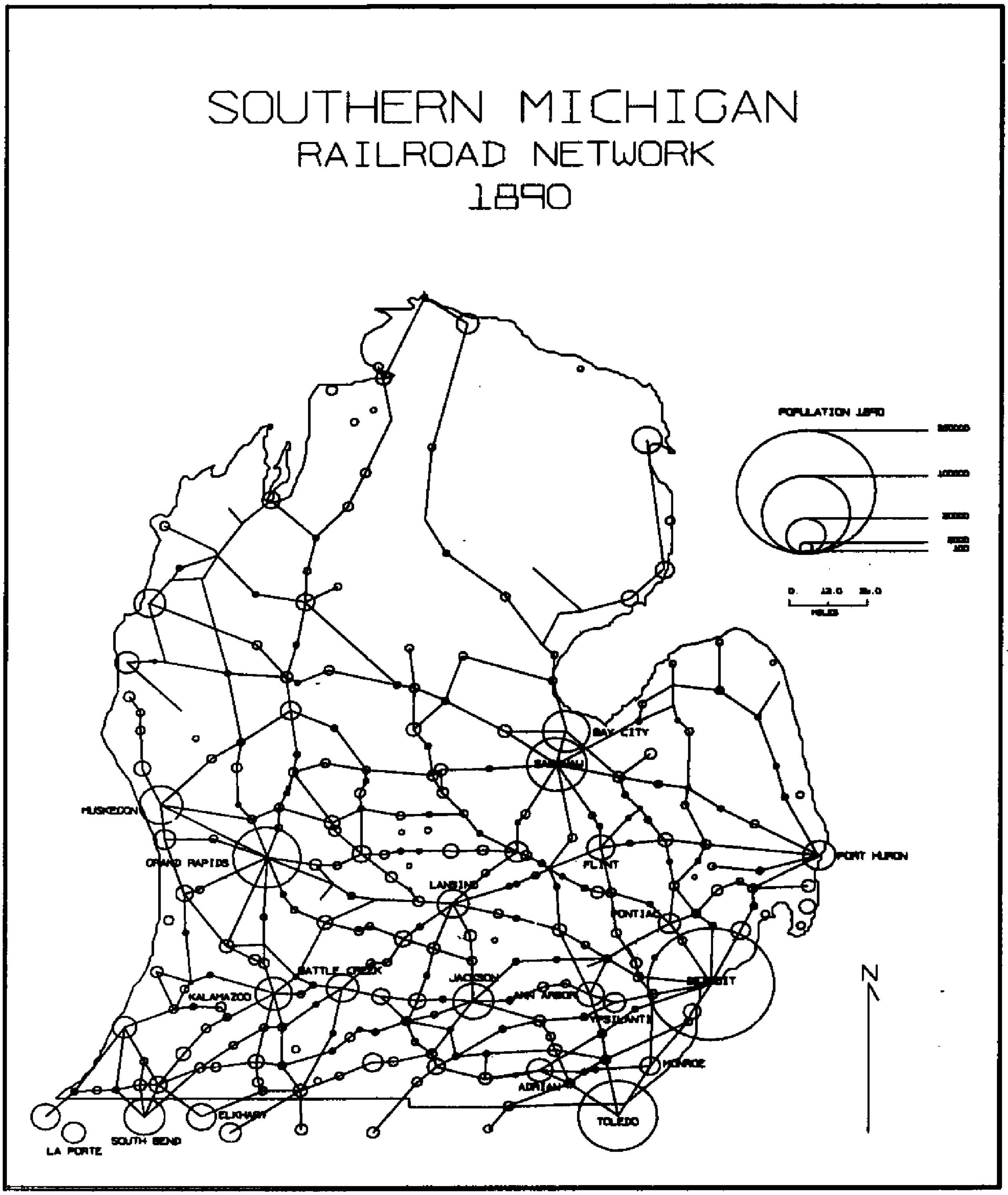
MAP 4


SOUTHERN MICHIGAN
RAILROAD NETWORK
1880
POPULATION 1880
MILES
MANISTEE
MUSKEGON
GRAND HAVEN
BAY CITY
SAGINAW
FLINT
PORT HURON
LANSING
BATTLE CREEK
KALAMAZOO
ANN ARBOR
JACKSON
ADRIAN
TOLEDO
ELKHART
SOUTH BEND
LA PORTE
N

MAP 5


SOUTHERN MICHIGAN
RAILROAD NETWORK
LINKS CONSTRUCTED
1880-1890
POPULATION 1880
MANISTEE
MUSKEGON
GRAND HAVEN
GRAND RAPIDS
LANSING
BAY CITY
SAGINAW
FLINT
PORT HURON
BATTLE CREEK
KALAMAZOO
ANN ARBOR
JACKSON
DETROIT
ADRIAN
TOLEDO
ELKHART
SOUTH BEND
LA PORTE
N

MAP 6


SOUTHERN MICHIGAN
RAILROAD NETWORK
1890
POPULATION 1890
MILES
N
MUSKEGON
GRAND RAPIDS
LANSING
BAY CITY
SAGINAW
FLINT
PORT HURON
PONTIAC
DETROIT
KALAMAZOO
BATTLE CREEK
JACKSON
ANN ARBOR
YPSILANTI
MONROE
ADRIAN
TOLEDO
ELKHART
SOUTH BEND
LA PORTE

MAP 7

from the main lines to bring the lumber out of the areas of major cutting activity.[9]

During this period there was still a significant amount of development in the southern part of the state where interconnection continued to take place. By 1890 the network in this part of the state was at its approximate maximum extent. The net increase in the length of the network in this area was less than two percent in the next thirty years.

The Period of Mixed Change: 1890-1920

Between 1890 and 1910 (see Maps 7-12) eighty percent of the expansion of the network occurred in the northern part of the state. In general this could be thought of as the period of interconnection for the northern part of the study area, although because of the lower density of population centers it was never carried to the extreme of the southern portion of the state.

During these two decades there were a few short links abandoned in various parts of the network, the majority of which were located in the northern region. Most of these links reflected an overly optimistic extension of the railroad into lumbering areas that could not support a railroad

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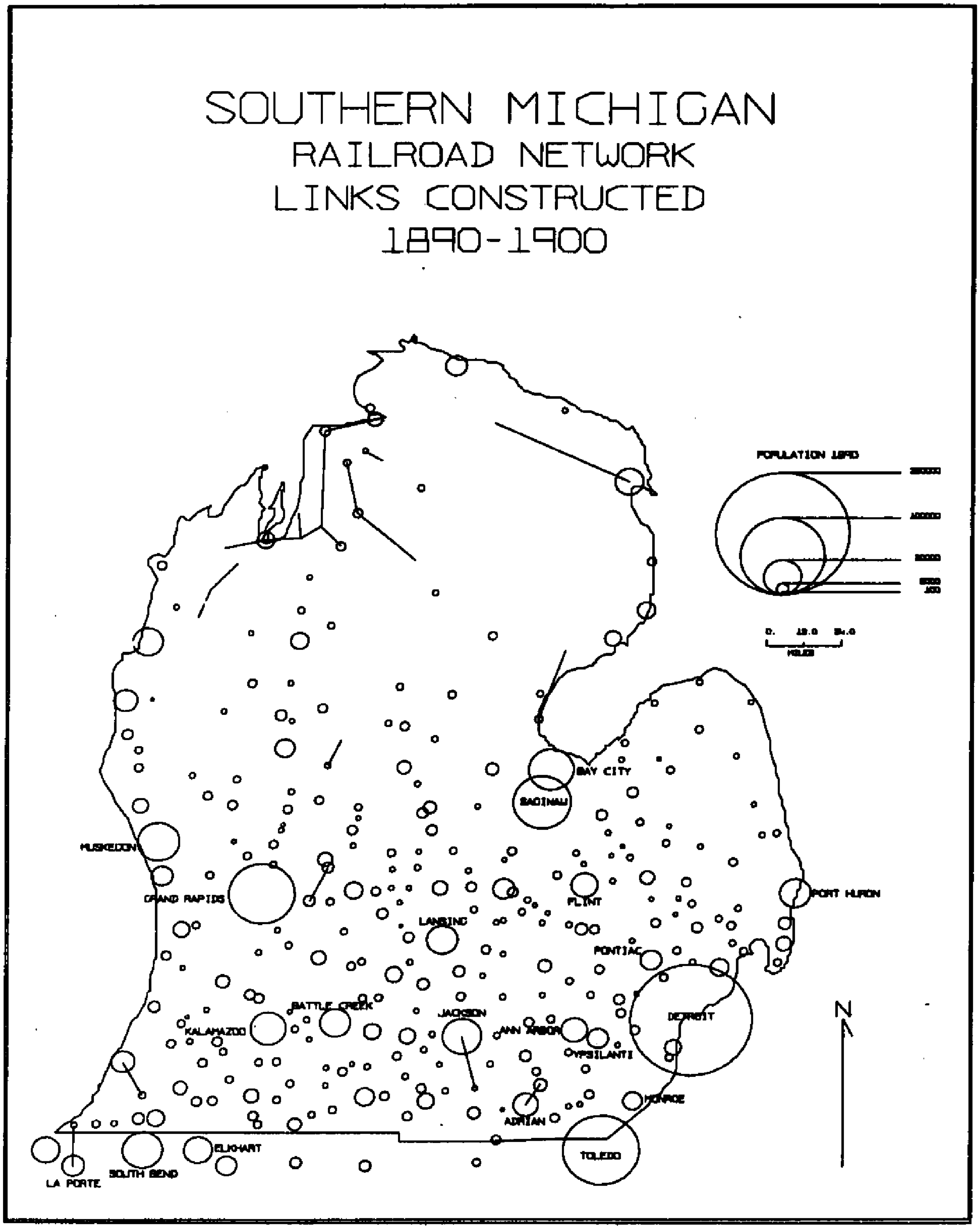
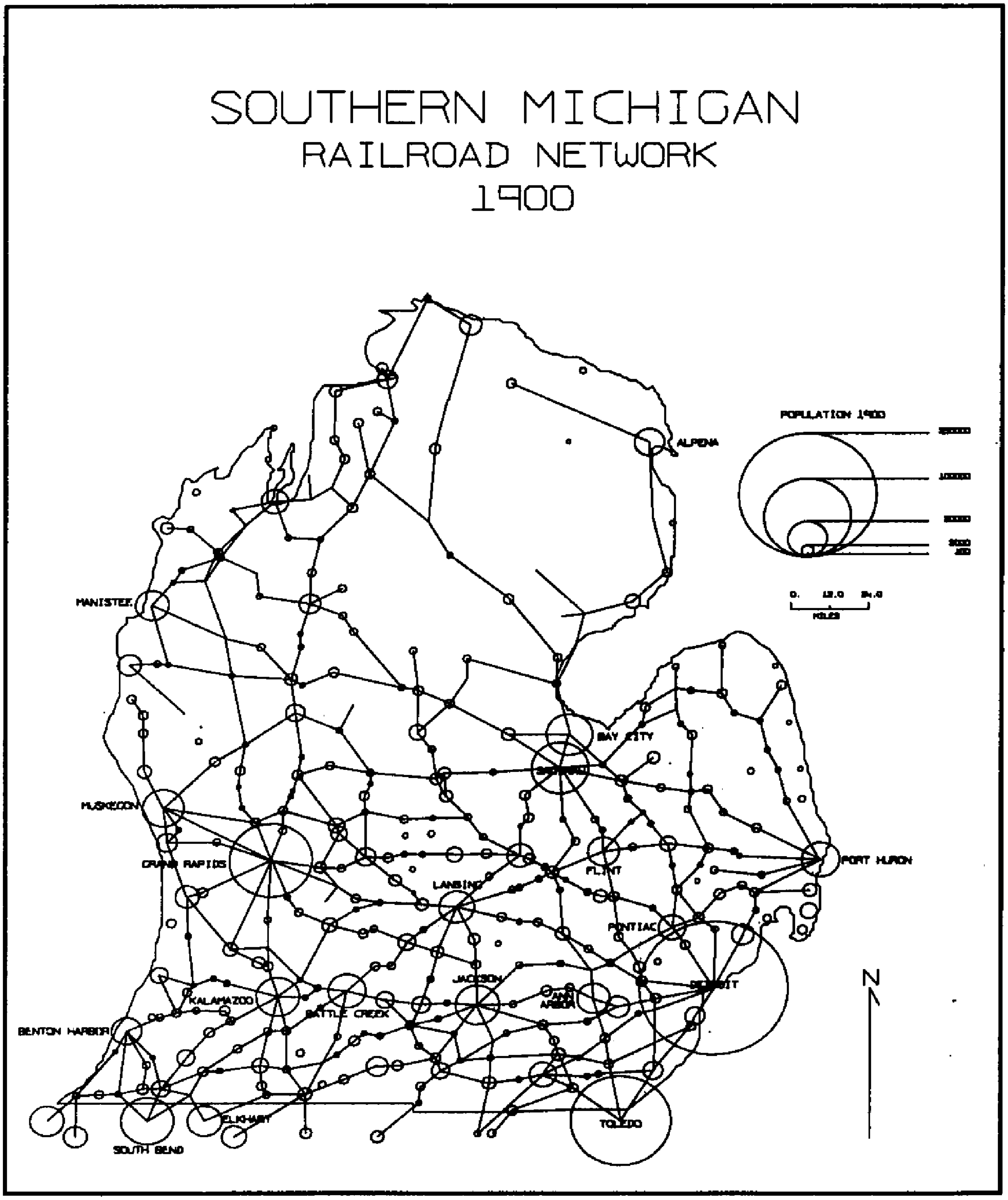
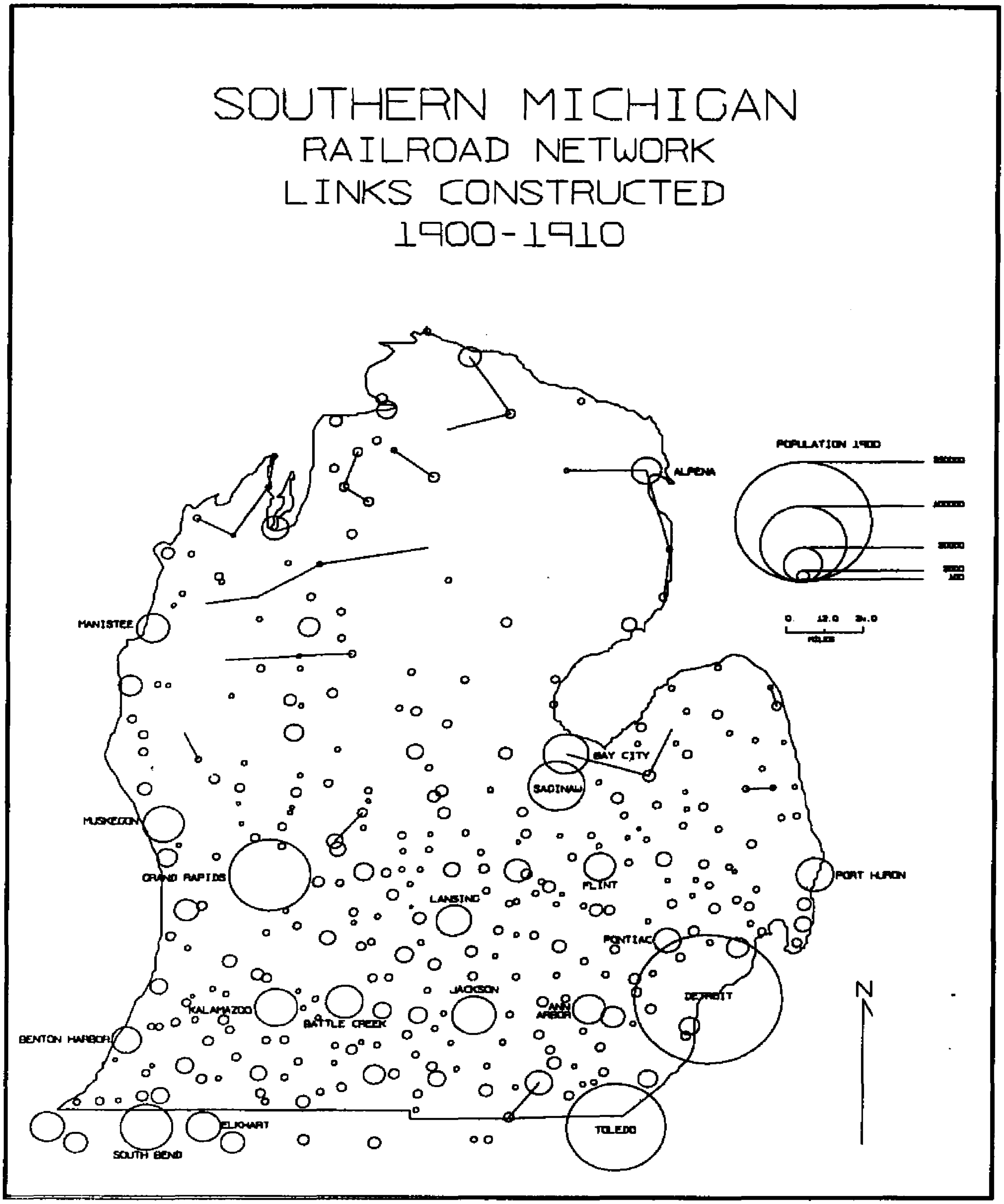
[9]These short links are not considered in this research since they were built to facilitate the exploitation of a resource and not to promote two way interaction. In many cases the interior nodes were lumber camps or small towns which were never incorporated and have completely disappeared.


SOUTHERN MICHIGAN
RAILROAD NETWORK
LINKS CONSTRUCTED
1890-1900
MUSKEGON
GRAND RAPIDS
LANSING
BAY CITY
SAGINAW
FLINT
PORT HURON
PONTIAC
DETROIT
BATTLE CREEK
KALAMAZOO
JACKSON
ANN ARBOR
YPSILANTI
MONROE
ADRIAN
TOLEDO
ELKHART
SOUTH BEND
LA PORTE
N

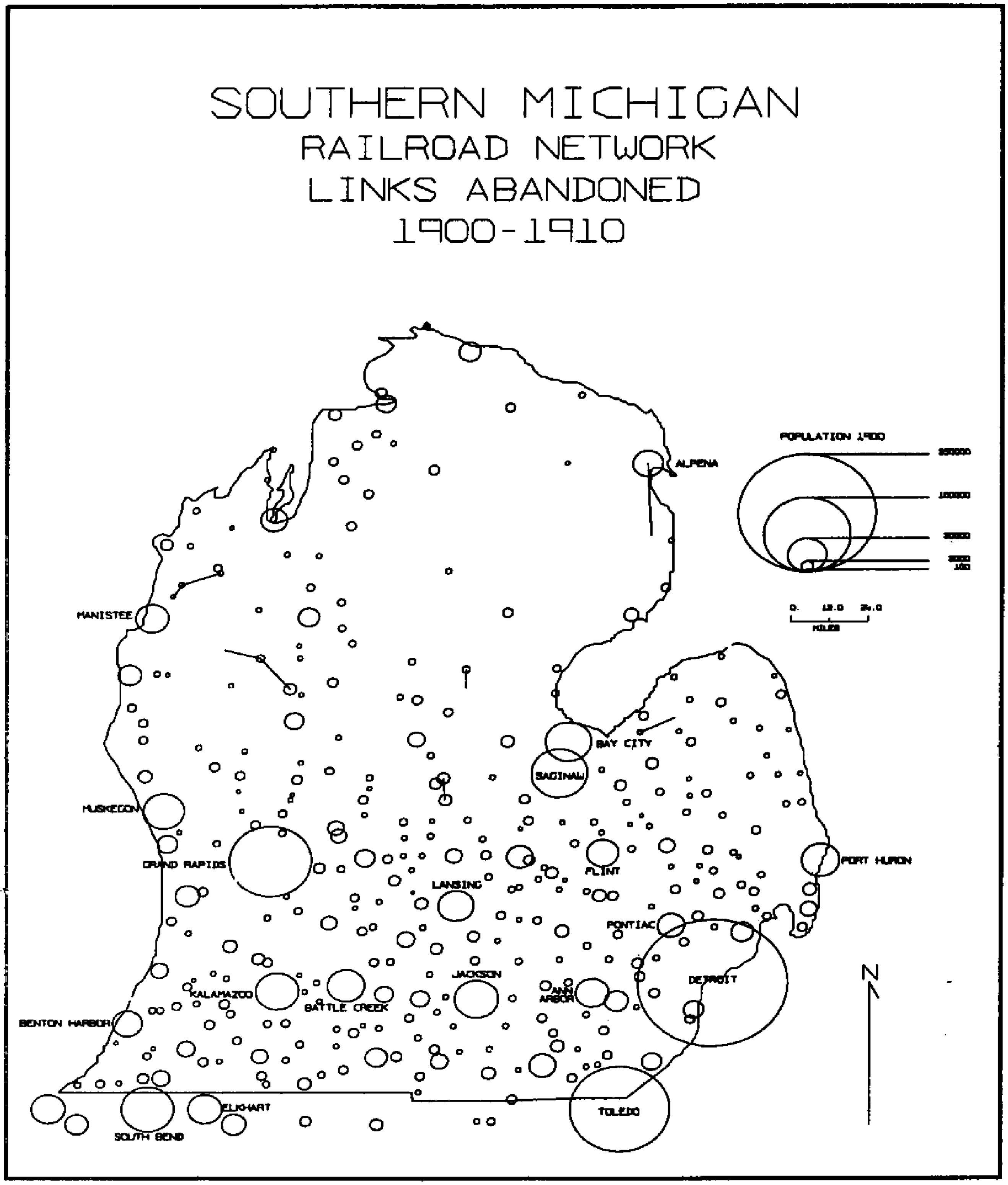
MAP 8


SOUTHERN MICHIGAN
RAILROAD NETWORK
1900
POPULATION 1900
ALPENA
MANISTEE
BAY CITY
MUSKEGON
GRAND RAPIDS
FLINT
PORT HURON
LANSING
PONTIAC
DETROIT
KALAMAZOO
JACKSON
ANN ARBOR
BATTLE CREEK
BENTON HARBOR
ELKHART
SOUTH BEND
TOLEDO
MILES
N

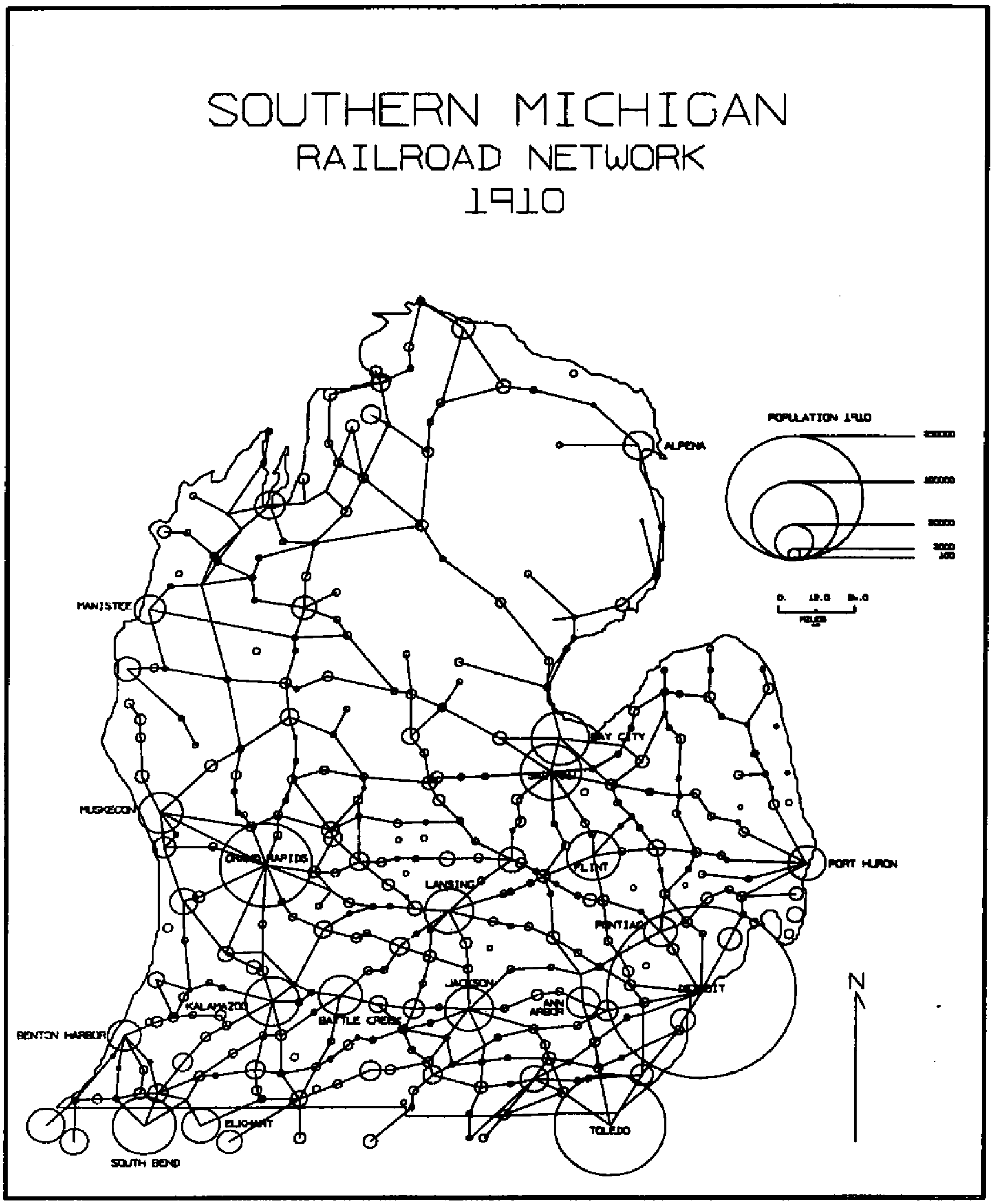
MAP 9


SOUTHERN MICHIGAN
RAILROAD NETWORK
LINKS CONSTRUCTED
1900-1910
POPULATION 1900
ALPENA
MANISTEE
BAY CITY
SAGINAW
MUSKEGON
GRAND RAPIDS
LANSING
FLINT
PORT HURON
PONTIAC
KALAMAZOO
BATTLE CREEK
JACKSON
ANN ARBOR
DETROIT
BENTON HARBOR
ELKHART
SOUTH BEND
TOLEDO
N

MAP 10


SOUTHERN MICHIGAN
RAILROAD NETWORK
LINKS ABANDONED
1900-1910
POPULATION 1900
ALPENA
MANISTEE
BAY CITY
SAGINAW
MUSKEGON
GRAND RAPIDS
LANSING
FLINT
PORT HURON
PONTIAC
DETROIT
JACKSON
KALAMAZOO
BATTLE CREEK
ANN ARBOR
BENTON HARBOR
ELKHART
SOUTH BEND
TOLEDO
N

MAP 11


SOUTHERN MICHIGAN
RAILROAD NETWORK
1910
POPULATION 1910
ALPENA
MANISTEE
MUSKEGON
BAY CITY
GRAND RAPIDS
FLINT
PORT HURON
LANSING
PONTIAC
JACKSON
DETROIT
ANN ARBOR
KALAMAZOO
BATTLE CREEK
BENTON HARBOR
ELKHART
SOUTH BEND
TOLEDO
N

MAP 12

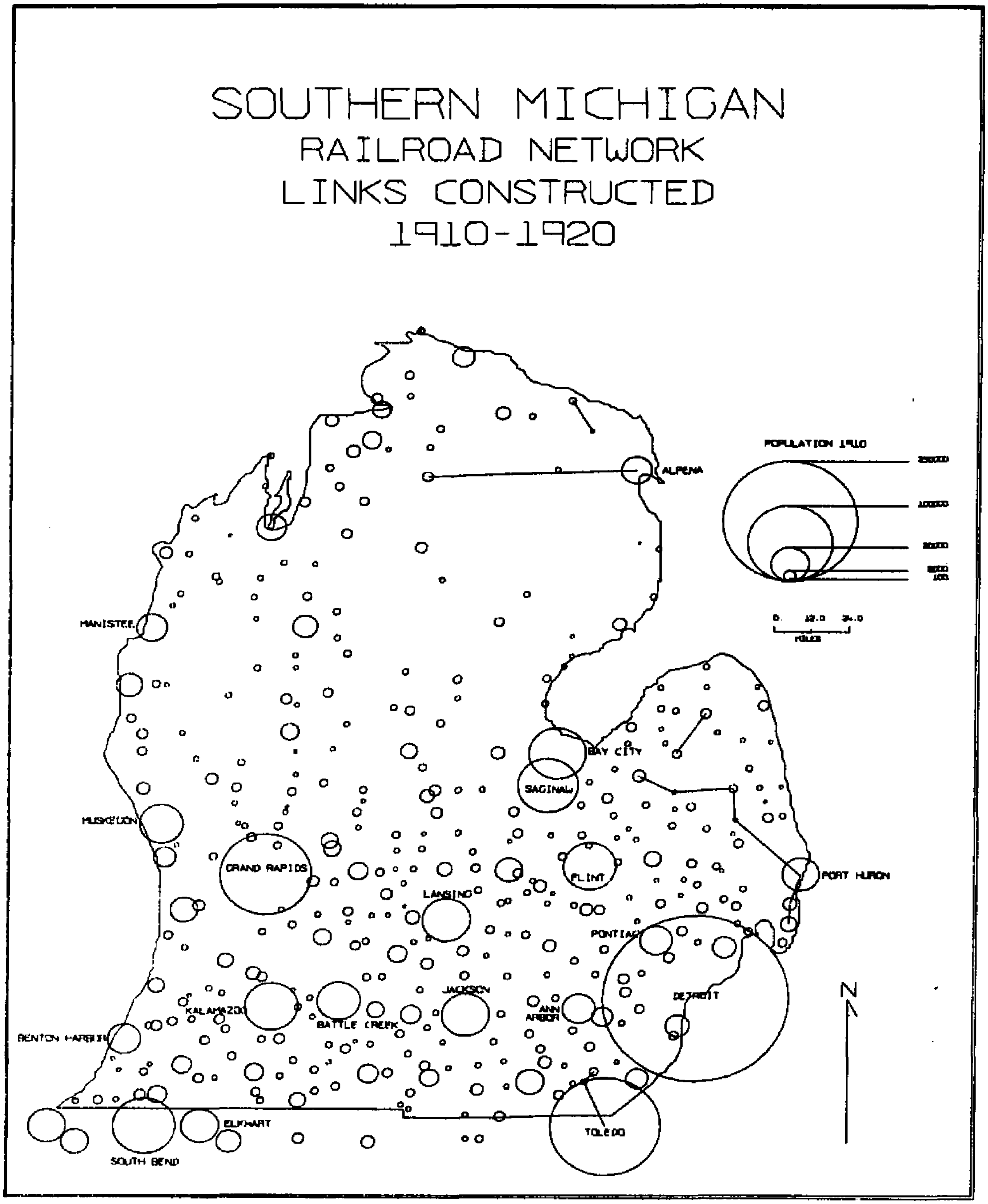
once all the timber was cut.

The growth and decline took on a different character from 1910-1920 (see Maps 12-15). Most of the additions to the network were in the thumb area of Michigan. The decline of the network during this period was more extensive than in the previous two decades; much longer segments of the network were abandoned. It was also notable that most of these abandonments were in the area of Traverse City, the region in the northern half of the study area with the greatest density of links. Moreover, the links that were dropped from the network were seldom over twenty years old. Thus they represented poor location decisions with regard to long term profitability.

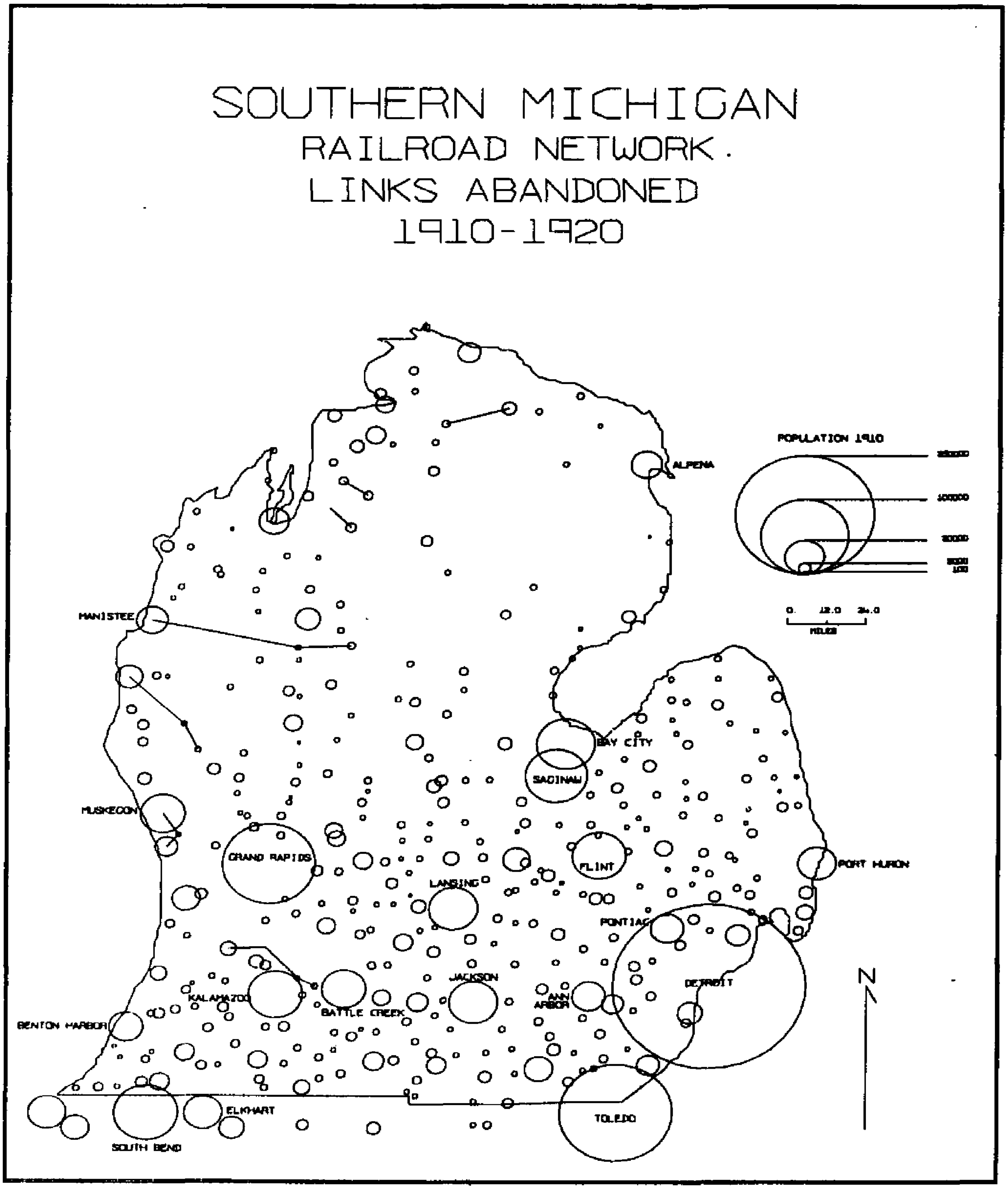
Decline of the Network: 1920-1967

From 1920 to 1930 (see Maps 15-17) the majority of the links abandoned were located in the northern half of the state, although not to the same extent as during the previous ten year period. Again many of the links which were removed from the network were located in the vicinity of Traverse City, indicating that there was still a significant degree of over servicing of the area by the network -- even after the extensive reduction during the previous decade.

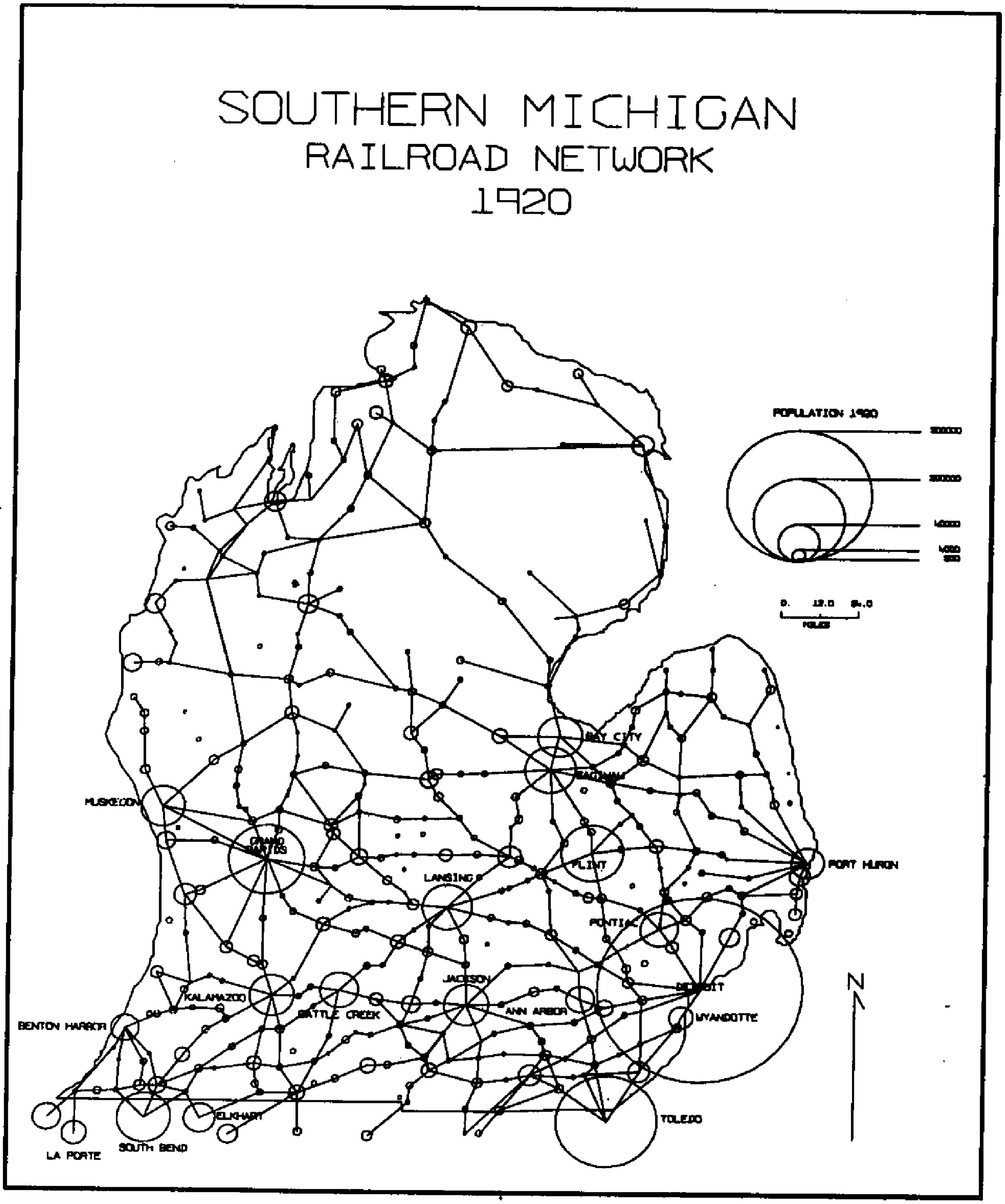
Between 1930 and 1942 (see Maps 17-19) there was the maximum reduction in the physical extent of the network; 380 miles were abandoned (see Table 2), much of which was in the


SOUTHERN MICHIGAN
RAILROAD NETWORK
LINKS CONSTRUCTED
1910-1920
ALPENA
MANISTEE
MUSKEGON
GRAND RAPIDS
LANSING
SAGINAW
BAY CITY
FLINT
PORT HURON
PONTIAC
DETROIT
JACKSON
ANN ARBOR
KALAMAZOO
BATTLE CREEK
BENTON HARBOR
ELKHART
SOUTH BEND
TOLEDO
POPULATION 1910
N

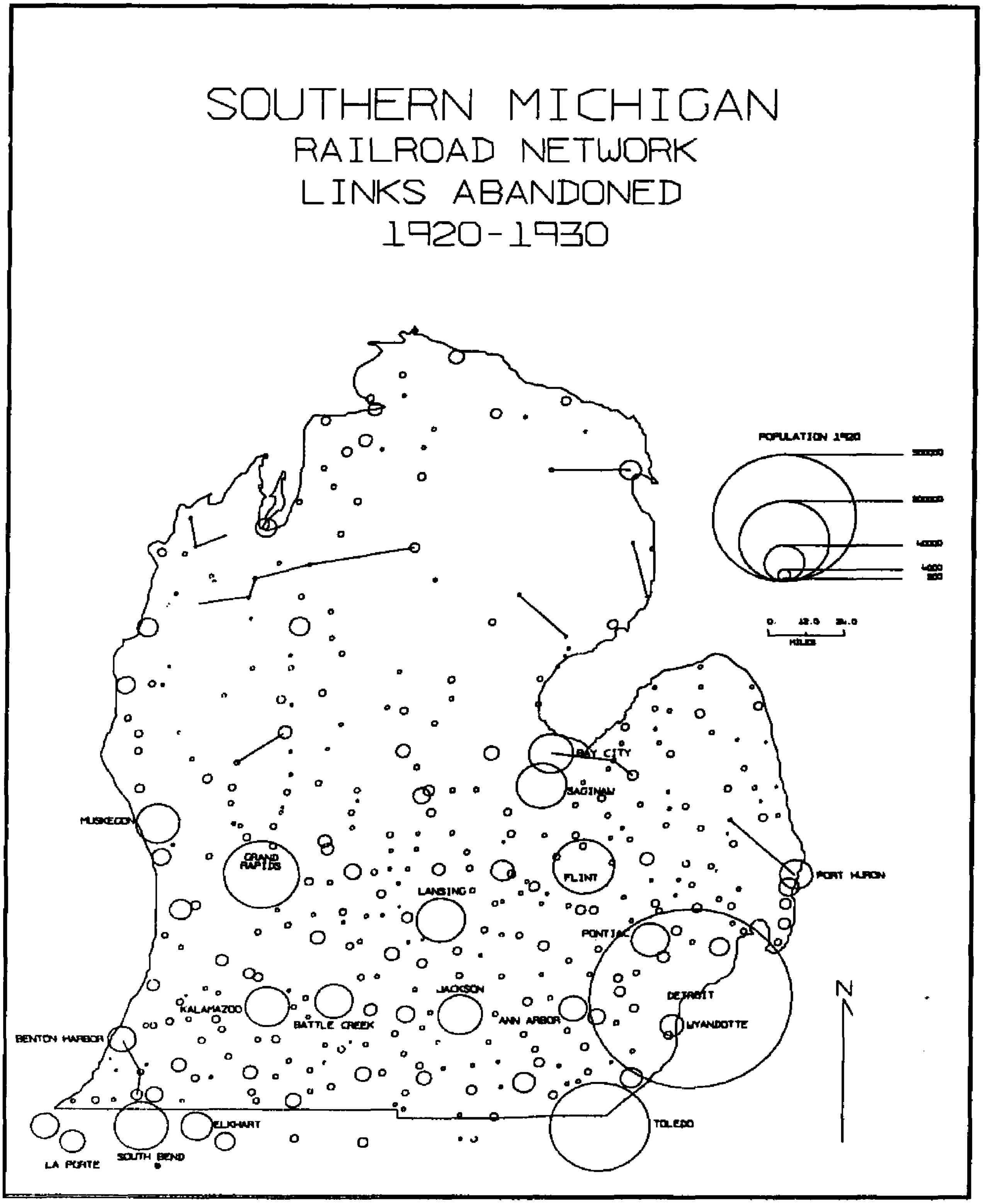
MAP 13


SOUTHERN MICHIGAN
RAILROAD NETWORK
LINKS ABANDONED
1910-1920
POPULATION 1910
ALPENA
MANISTEE
MUSKEGON
GRAND RAPIDS
LANSING
BAY CITY
SAGINAW
FLINT
PORT HURON
PONTIAC
DETROIT
KALAMAZOO
BATTLE CREEK
JACKSON
ANN ARBOR
BENTON HARBOR
ELKHART
SOUTH BEND
TOLEDO
N

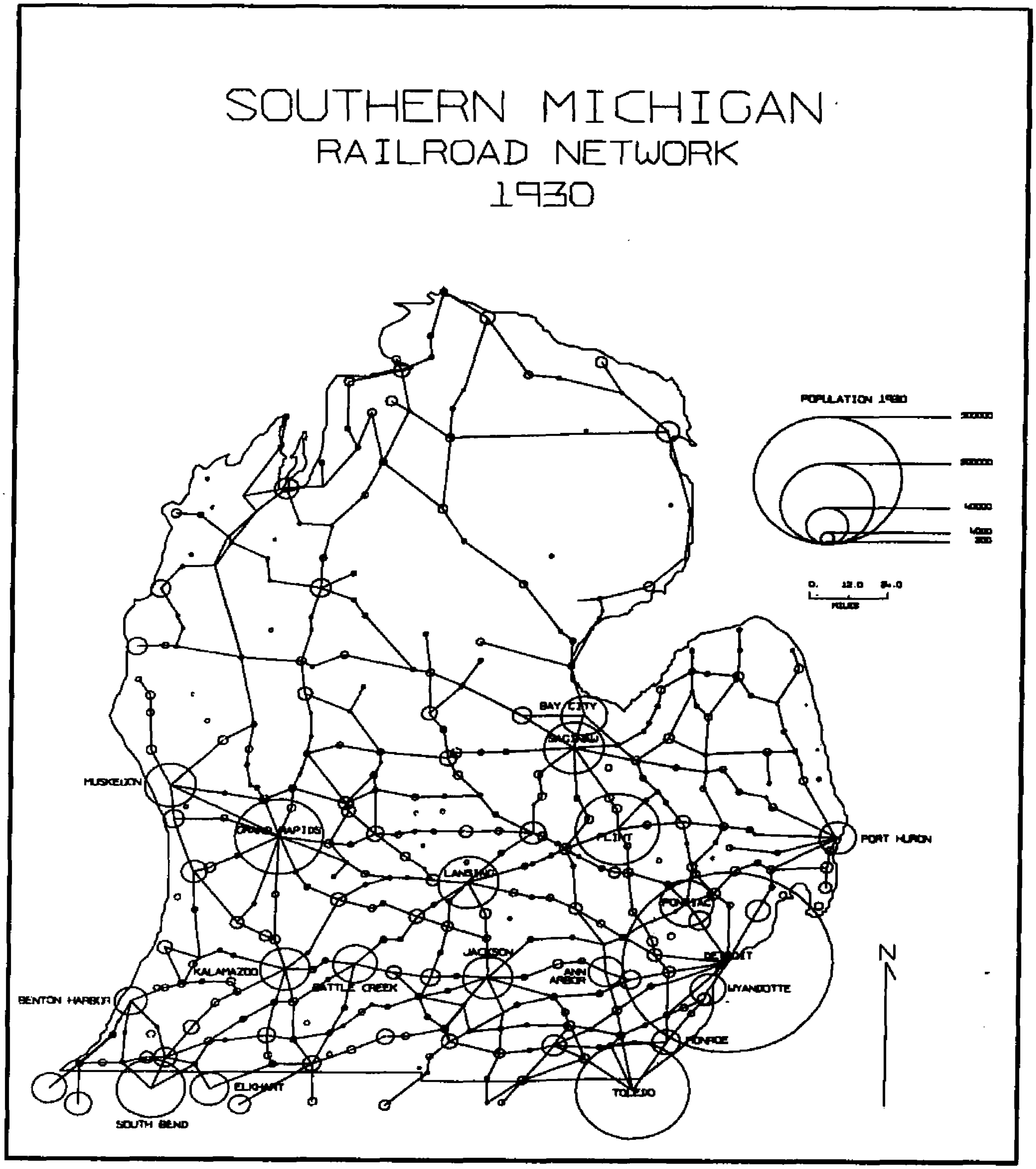
MAP 14


SOUTHERN MICHIGAN
RAILROAD NETWORK
1920
POPULATION 1920
MUSKEGON
GRAND RAPIDS
LANSING
FLINT
BAY CITY
SAGINAW
PORT HURON
PONTIAC
DETROIT
WYANDOTTE
KALAMAZOO
BATTLE CREEK
JACKSON
ANN ARBOR
BENTON HARBOR
ELKHART
SOUTH BEND
LA PORTE
TOLEDO
N

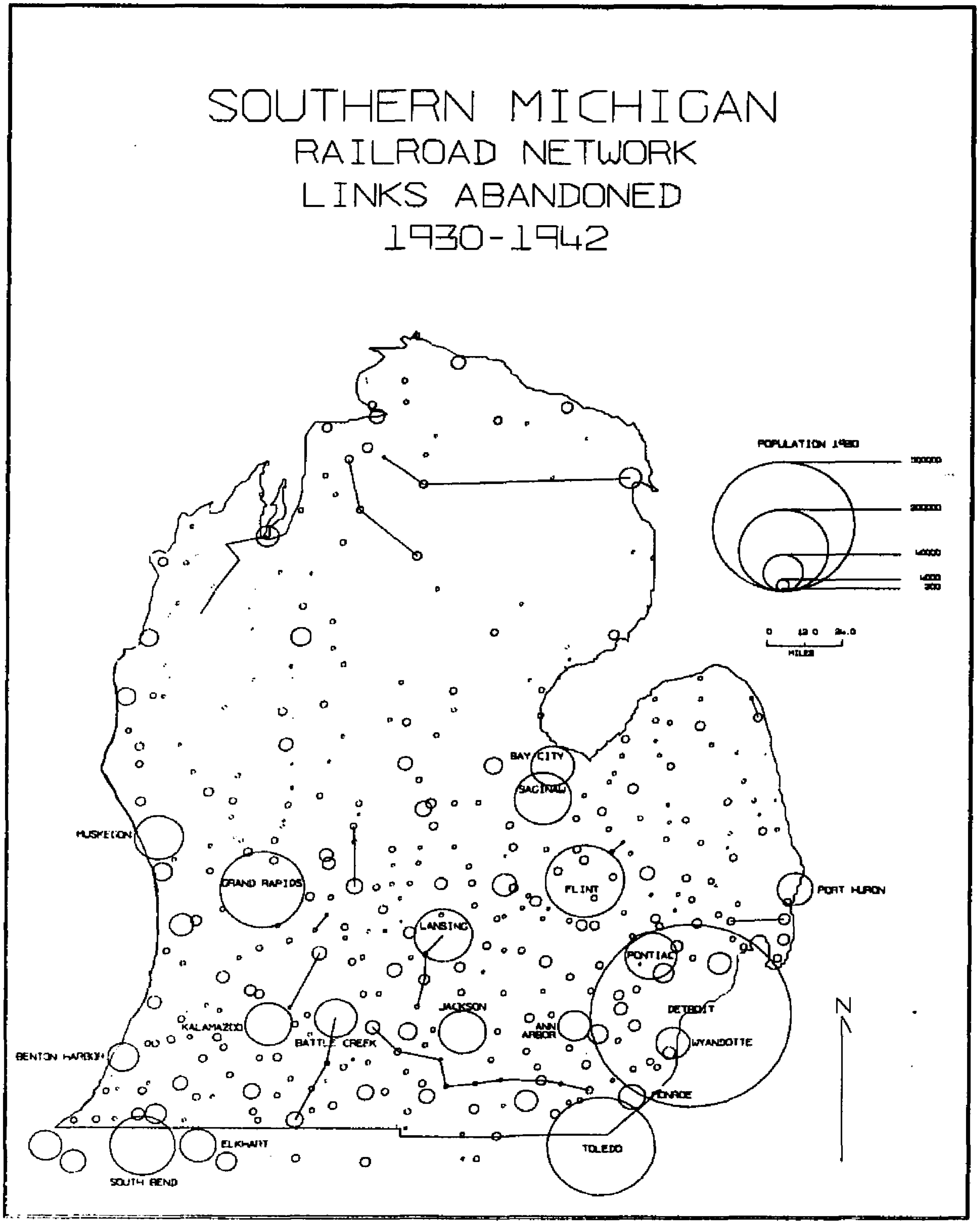
MAP 15


SOUTHERN MICHIGAN
RAILROAD NETWORK
LINKS ABANDONED
1920-1930
POPULATION 1920
MUSKEGON
GRAND RAPIDS
LANSING
BAY CITY
SAGINAW
FLINT
PORT HURON
PONTIAC
DETROIT
WYANDOTTE
KALAMAZOO
BATTLE CREEK
JACKSON
ANN ARBOR
BENTON HARBOR
ELKHART
SOUTH BEND
LA PORTE
TOLEDO
N

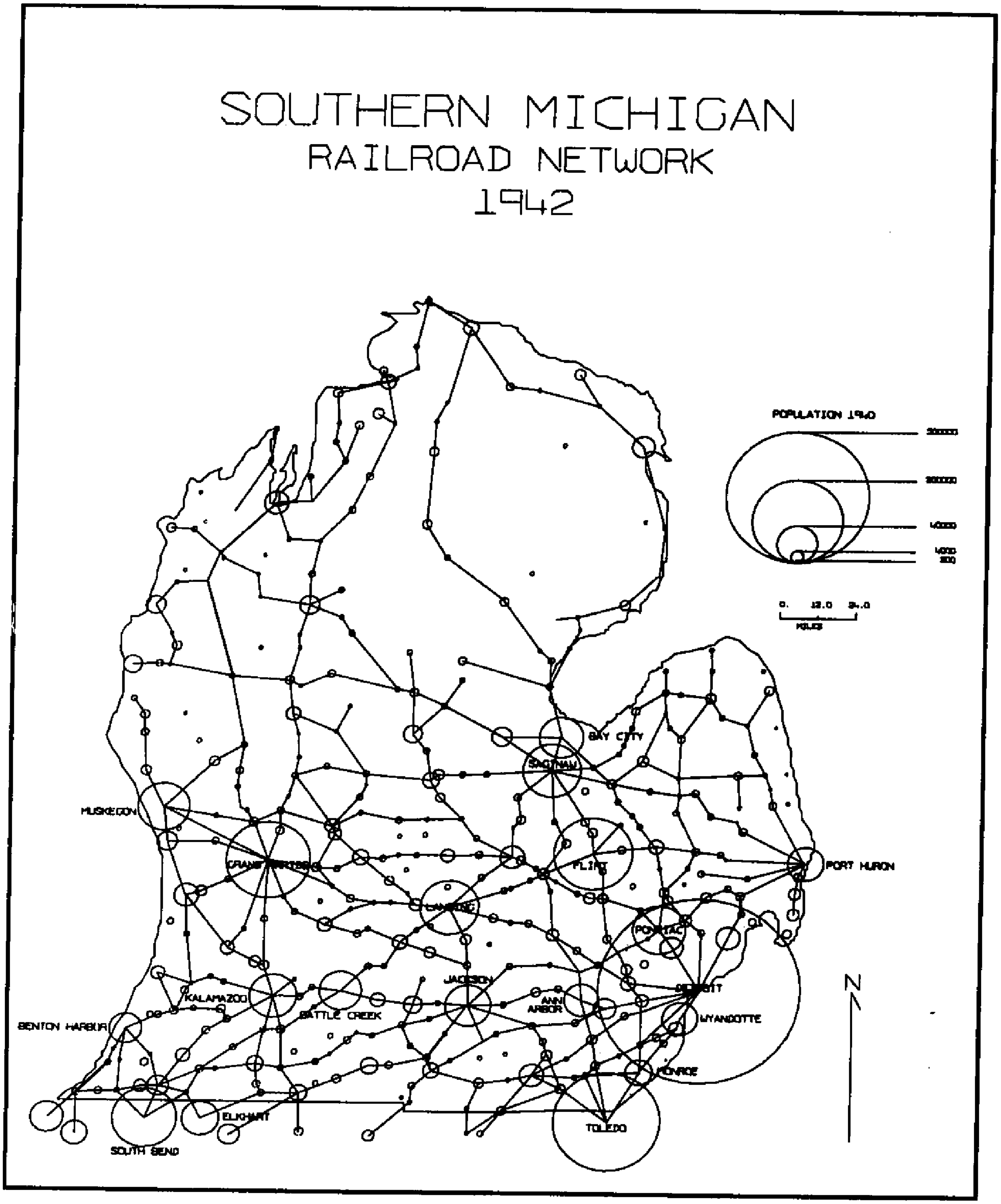
MAP 16


SOUTHERN MICHIGAN
RAILROAD NETWORK
1930
POPULATION 1930
MUSKEGON
GRAND RAPIDS
BAY CITY
SAGINAW
FLINT
PORT HURON
LANSING
PONTIAC
DETROIT
WYANDOTTE
JACKSON
ANN ARBOR
KALAMAZOO
BATTLE CREEK
BENTON HARBOR
MONROE
TOLEDO
ELKHART
SOUTH BEND
N

MAP 17


SOUTHERN MICHIGAN
RAILROAD NETWORK
LINKS ABANDONED
1930-1942
BAY CITY
SAGINAW
MUSKEGON
GRAND RAPIDS
FLINT
PORT HURON
LANSING
PONTIAC
DETROIT
JACKSON
ANN ARBOR
KALAMAZOO
BATTLE CREEK
WYANDOTTE
BENTON HARBOR
MONROE
ELKHART
TOLEDO
SOUTH BEND
N

MAP 18


SOUTHERN MICHIGAN
RAILROAD NETWORK
1942
POPULATION 1940
MUSKEGON
BAY CITY
SAGINAW
FLINT
PORT HURON
LANSING
PONTIAC
KALAMAZOO
BATTLE CREEK
JACKSON
ANN ARBOR
WYANDOTTE
BENTON HARBOR
MONROE
ELKHART
TOLEDO
SOUTH BEND
N

MAP 19

southern half of the study area for the first time. This twelve year period marks the last significant decline of the network in the northern part of the state.

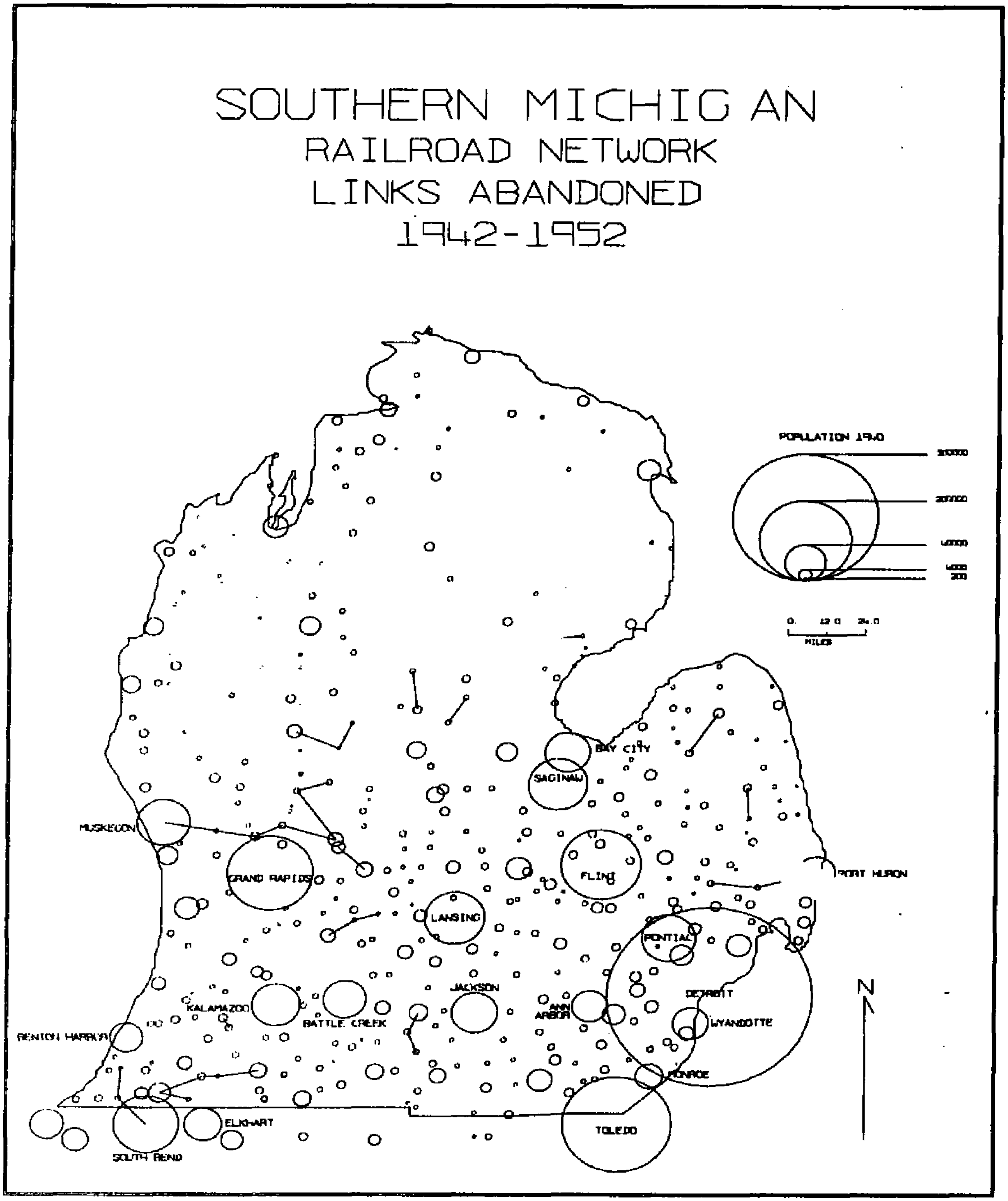
The major abandonments in the southern half of the state were a series of links running from Marshall (east of Battle Creek) to Dundee (west of Monroe), from Battle Creek south to Sturgis, and from Lansing south to Springport. In the northern region several links were again abandoned in the northwestern section around Traverse City. The network in this area was less extensive in 1942 than it was in 1900.

From 1942 to 1967 (see Maps 19-22) there was a trend for small sections or single links to be removed from the network. The largest segment of the network to be abandoned was the section north of Grand Rapids running between Muskegon and Greenville.

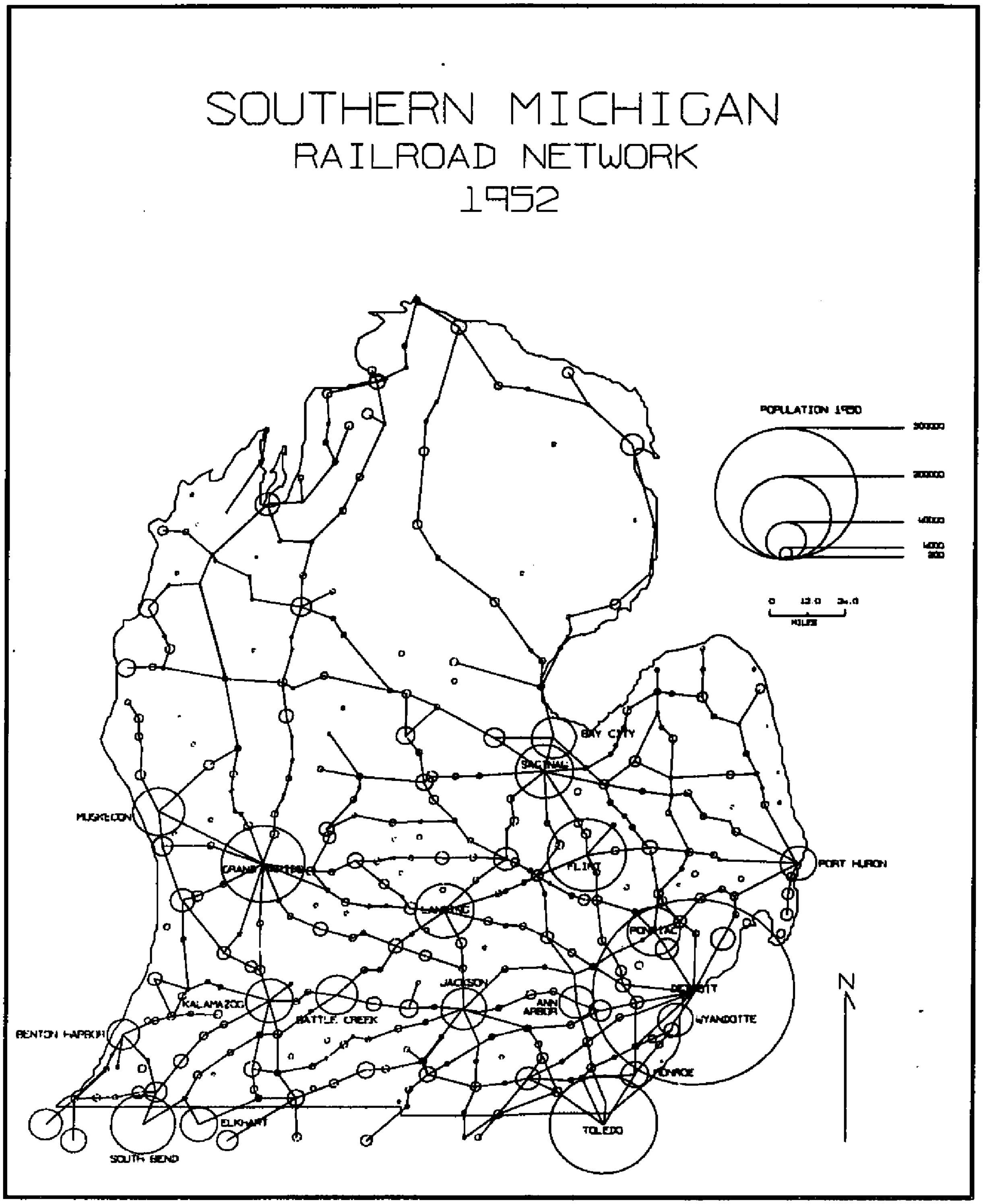
Summary

1860-1890--Between 1860 and 1890, 98 percent of the growth of the network in the southern region took place. Interconnection of the nodes linked by the three major lines of penetration opened prior to 1860 was the primary form of growth. The initial lines of penetration were built in the northern part of the state during this period, with the goal being to make connections to Mackinaw City.

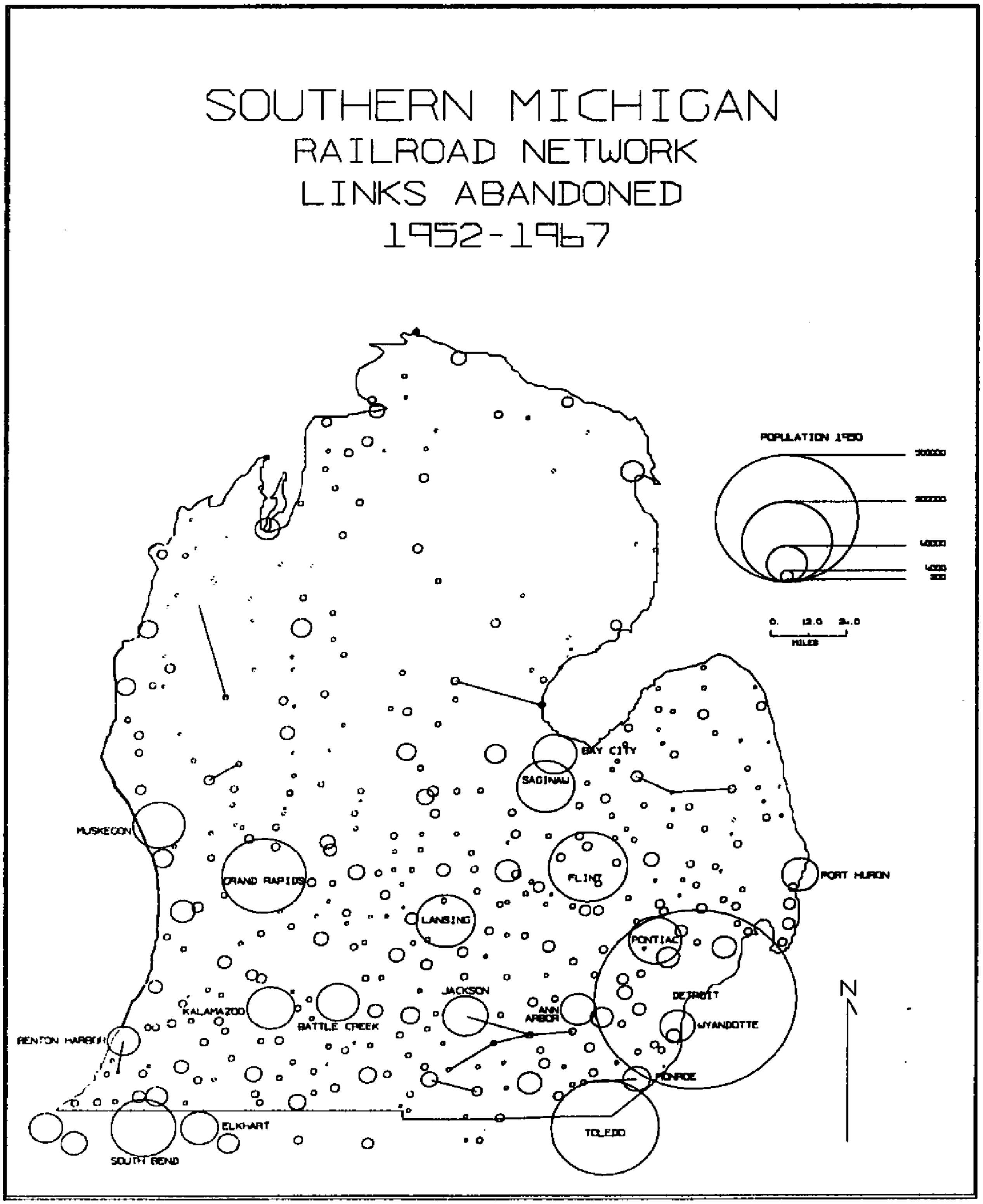
1890-1920--Most of the growth from 1890 to 1920 was in the northern part of the study area and a significant


SOUTHERN MICHIGAN
RAILROAD NETWORK
LINKS ABANDONED
1942-1952
POPULATION 1940
MUSKEGON
GRAND RAPIDS
LANSING
BAY CITY
SAGINAW
FLINT
PORT HURON
PONTIAC
DETROIT
WYANDOTTE
JACKSON
ANN ARBOR
KALAMAZOO
BATTLE CREEK
BENTON HARBOR
MONROE
TOLEDO
ELKHART
SOUTH BEND
MILES
N

MAP 20


SOUTHERN MICHIGAN
RAILROAD NETWORK
1952
MUSKEGON
BAY CITY
PORT HURON
FLINT
LANSING
JACKSON
KALAMAZOO
BATTLE CREEK
ANN ARBOR
WYANDOTTE
BENTON HARBOR
MONROE
ELKHART
TOLEDO
SOUTH BEND
N

MAP 21


SOUTHERN MICHIGAN
RAILROAD NETWORK
LINKS ABANDONED
1952-1967
POPULATION 1950
MILES
BAY CITY
SAGINAW
MUSKEGON
GRAND RAPIDS
FLINT
PORT HURON
LANSING
PONTIAC
DETROIT
WYANDOTTE
JACKSON
ANN ARBOR
KALAMAZOO
BATTLE CREEK
BENTON HARBOR
MONROE
TOLEDO
ELKHART
SOUTH BEND
N

MAP 22

proportion of these additions did not remain in the network for over twenty years. The area adjacent to and south of Traverse City contained an especially large number of links which had a short life. The short duration of these links was in part related to the initial reasons for the construction being to serve the short lived lumbering industry. Lumbering was not replaced by a farming or industrial economy after the lumber supply was depleted as occurred in the southern part of the state.

During the 1890 to 1920 period the network south of Bay City was relatively stable. The thumb area was the only portion of this region that experienced any moderate change.

<u>1920-1967</u>--The period after 1920 was one of exclusive network decline over the entire study area. A partial explanation for many of the abandonments was that they represented duplications of services. After all of the links were abandoned most of the nodes that were connected to the network in 1920 were still joined to the network. The only exceptions were some of the smaller towns.

The network looked much more "tree-like" in structure in 1967 than it did even in 1890. There was a change from minimizing distance between points on the network to minimizing the length of the network. With the rise of the competitive modes of transportation, the nodes that once generated sufficient traffic to be located on the main line of the network only generated enough to be located on a branch line. Thus there was a rising of the general threshold of the centers that were connected to the network.

CHAPTER V

GROWTH OF THE RAILROAD NETWORK OF SOUTHERN MICHIGAN

The purpose of this chapter is to determine how well the three hypothesized concepts--locally generated interaction, path effect, and the field effect--explain the growth of the railroad network of southern Michigan between 1860 and 1920. The major proportion of the growth of the network took place during this six decade period; only five percent of the growth occurred prior to 1860, and less than one percent took place after 1920.

A discriminant analysis model is produced for each of the six decades. The two groups of alternatives used in the models are 1) the links constructed and 2) the potential links rejected by the decision makers. The attributes used to differentiate between the two groups of alternatives are found in Table 1.

1860-1870

The railroad entrepreneurs in making their location decisions during the period between 1860 and 1870 were primarily influenced by the competition for locally generated interaction--the number and proportion of nodes joined to the network within the hinterland of the two nodes connected by the potential links (see Table 3).[1] The alternatives situated in areas served by rival railroad lines were rejected, while those in areas isolated from competition were accepted. The sizes of the nodes connected by the alternatives (variables 2 and 3) and the length of the potential links (variable 1) were of inconsequential effect on the location decisions, denoting that the decision makers' perception of the capacity of the link for generating local traffic was based solely on the location of competitive nodes.

The general lack of importance of the size of the potential nodes is related to the importance of the lumbering industry as the major source of revenue for the railroads. Apparently the entrepreneurs perceived the amount of potential lumber traffic to decrease as the number of competitive nodes served by the railroads increased.

There was some preference for alternatives adding the least distance to the nearest major inter-city route,[2] indicating the path effect was of importance in the decision making

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[1]The attributes ranking first, fifth, sixth, and seventh in contribution to discrimination between the two groups of alternatives--percentage of urban centers connected to the network within thirty miles of the potential link (variable 9), the number of nodes connected to the network within twenty miles of the potential link (variable 6), the number of nodes connected to the network within ten miles of the potential link (variable 4), the percentage of nodes connected to the network within ten miles of the potential link (variable 5)--indicate the avoidance of competitive nodes.

[2]The attribute ranking second in contribution to the discrimination between the two groups of alternatives was the

TABLE 3.--Rank and standardized weights of the discriminant function for the growth of the railroad network of southern Michigan from 1860 to 1870[a]

	Variable Number and Name	Standardized Weight	Rank
1.	Length of the alternative...........	.109	12
2.	Population of the larger node.......	. . .[b]	.
3.	Population of the smaller node......	. . .	.
4.	Number of urban centers connected to the network within ten miles of the alternative......................	-.226	6
5.	Percentage of urban centers connected to the network within ten miles of the alternative...........	-.221	7
6.	Number of urban centers connected to the network within twenty miles of the alternative..................	-.251	5
7.	Percentage of urban centers connected to the network within twenty miles of the alternative...........	. . .	.
8.	Number of urban centers connected to the network within thirty miles of the alternative..................	. . .	.
9.	Percentage of urban centers connected to the network within thirty miles of the alternative...........	-.501	1
10.	Number of connections to the smaller node................................	. . .	.
11.	Number of connections to the larger node................................	-.211	8
12.[c]	Distance to the nearest major urban-economic center.....................	-.360	4
13.	Distance to the second nearest major urban-economic center................	.194	9

TABLE 3.--Continued

	Variable Number and Name	Standardized Weight	Rank
14.[d]	Distance added to the nearest least cost path by the connection of the node closer to the path............	.099	13
15.	Distance added to the nearest least cost path by the alternative given the initial connection of the node closer to the path.................	. . .	.
16.	Distance added to the nearest least cost path by the alternative given the initial connection of the node farther from the path..............	-.400	2
17.	Population of the node closer to the path...........................	. . .	.
18.	Population of the node farther from the path...........................	. . .	.
19.	Alternative north of Bay City......	-.147	10
20.	Distance to the nearest urban center connected to the network......	-.394	3

[a]The mean score for the alternatives rejected was -1.083, for the alternatives accepted, -.680.

[b]The variables with standardized weights less than .1 or with high correlations with several other variables were dropped from the analysis, and the function was recalculated.

[c]The major urban-economic centers were defined as the ten largest cities.

[d]The least cost paths were defined as the routes between the ten largest cities.

process. However, there was no apparent trade-off of size of the nodes and the distance added to the least cost path by the potential link. A trade-off between the distance added to the path and the percentage of competitive nodes--nodes connected to the network--could be perceived; if this were so, then *ceteris paribus*, a decision maker would have been willing to extend the path one mile for each 3.1 percent reduction in the percentage of urban centers connected to the network within thirty miles of the alternative.

Proximity to the network also influenced the location decisions. The greater the distance to the nearest node connected to the network in 1860 (variable 20, rank 3), the less likely the alternative was accepted. Other things being equal, for every mile the alternative was located from a node connected to the network, an entrepreneur would have to have a 1.5 percent reduction in the number of competitive nodes, or a .5 mile reduction in the distance to the nearest least cost path.

The field effect had an impact on the location decisions. The alternatives nearest to one of the ten largest cities (variable 12, rank 4) were chosen over the more isolated links. But conversely the greater the distance to the second nearest large city (variable 13, rank 9), the more likely the alternative was accepted. These two

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distance added to the nearest least cost path by the alternative, given the initial connection of the node farther from the path (variable 16).

variables may be interpreted as indicating the entrepreneurs preferred locations sufficiently isolated to be able to exploit the lumber traffic, but still near a large urban node which could serve as a distribution point.

Using the discriminant scores, it is possible to predict 87 percent of all of the location decisions correctly, including 78 percent of the links constructed (see Map 23), and 89 percent of the alternatives rejected. The average of the latter two figures, 84 percent, is felt to be the best overall indicator of the predictive ability of the model, since the alternatives rejected form a larger group and are normally easier to predict. There are plausible explanation for most of the misclassifications.

Alternatives incorrectly rejected.--Three out of the seven links actually constructed but not predicted by the model (see Map 24) formed the initial part of the Michigan Air Line, a railroad company owned by the Grand Trunk Railroad. The purpose of the Michigan Air Line was to provide the Grand Trunk, having the western terminus at Port Huron, with a connection to Chicago. This linkage would place the Grand Trunk in a much better position to compete with the American railroads for the lucrative trade between Chicago and the Atlantic coast ports.[3]

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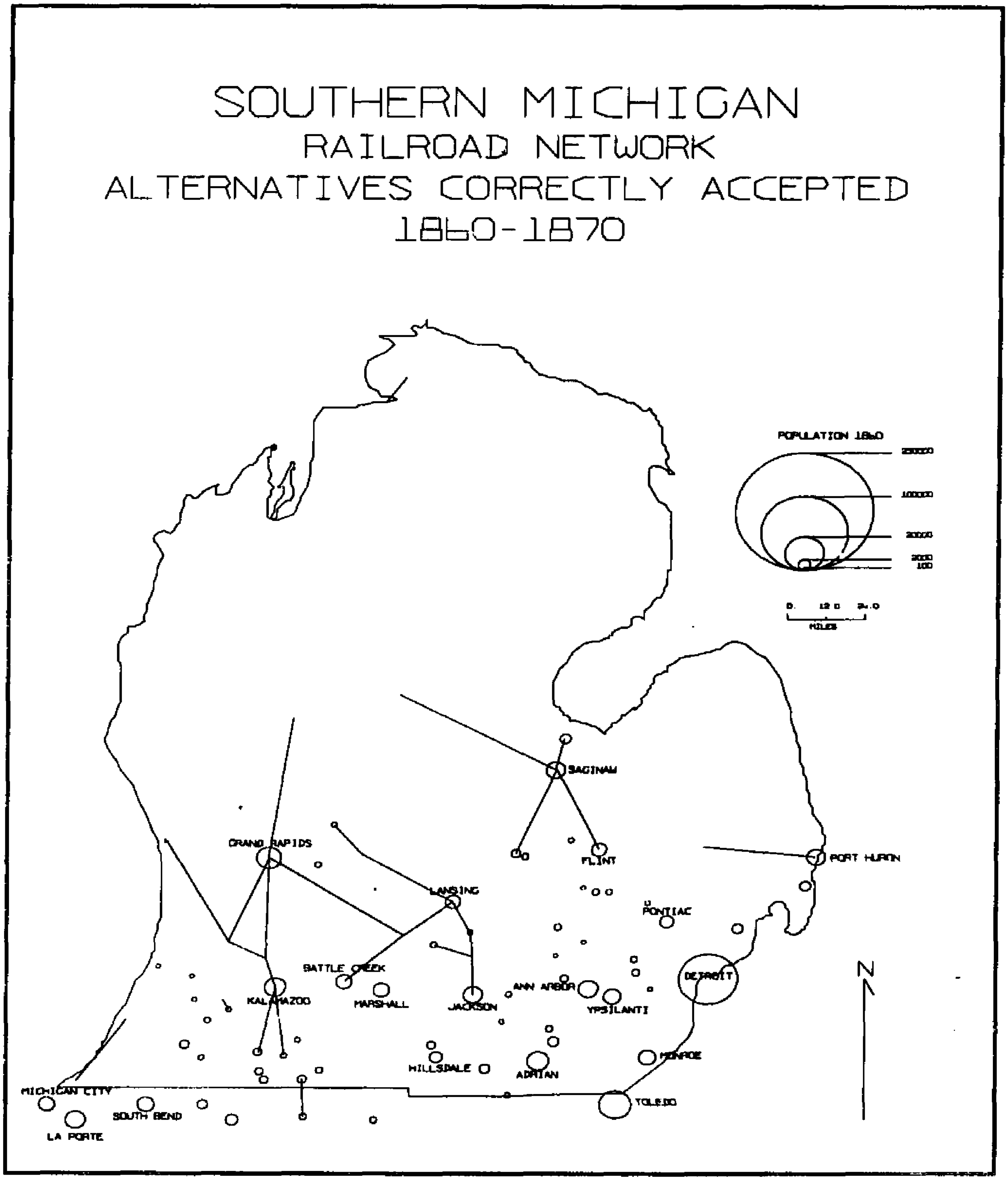
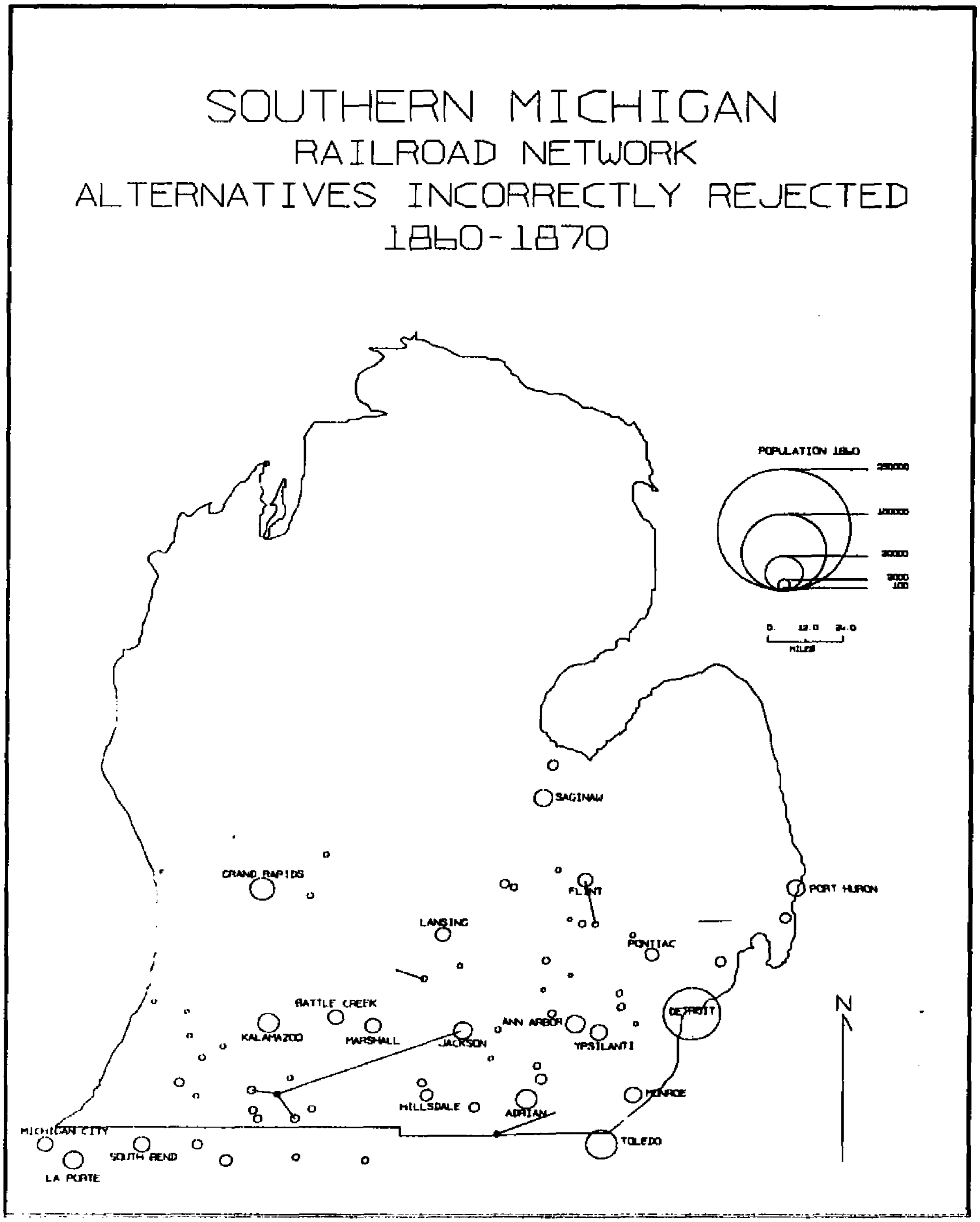
[3] A. W. Currie, The Grand Trunk Railroad of Canada (Toronto: The University of Toronto Press, 1957), pp. 222-29.


SOUTHERN MICHIGAN
RAILROAD NETWORK
ALTERNATIVES CORRECTLY ACCEPTED
1860-1870
SAGINAW
GRAND RAPIDS
FLINT
PORT HURON
LANSING
PONTIAC
BATTLE CREEK
KALAMAZOO
MARSHALL
JACKSON
ANN ARBOR
YPSILANTI
DETROIT
HILLSDALE
ADRIAN
MONROE
MICHIGAN CITY
SOUTH BEND
LA PORTE
TOLEDO
N

MAP 23

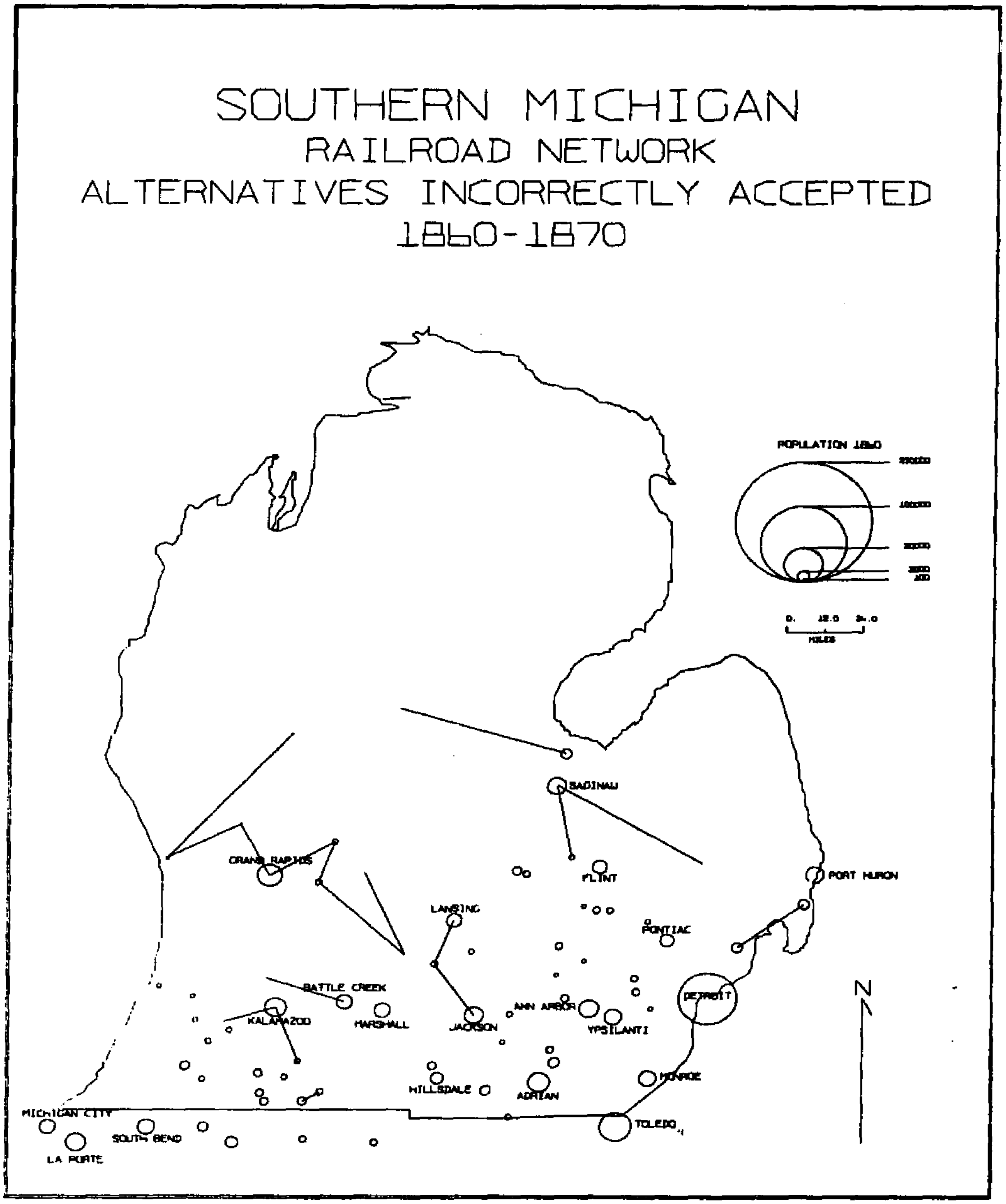

SOUTHERN MICHIGAN
RAILROAD NETWORK
ALTERNATIVES INCORRECTLY REJECTED
1860-1870
POPULATION 1860
SAGINAW
GRAND RAPIDS
FLINT
PORT HURON
LANSING
PONTIAC
BATTLE CREEK
DETROIT
KALAMAZOO
MARSHALL
JACKSON
ANN ARBOR
YPSILANTI
HILLSDALE
ADRIAN
MONROE
MICHIGAN CITY
SOUTH BEND
TOLEDO
LA PORTE
N

MAP 24

The four remaining links which are misclassified formed parts of intercity routes. The link between Eaton Rapids and Charlotte (south of Lansing) was a section of the route between Jackson and Grand Rapids. Similarly the links between Mendon and Centreville, and Centreville and Sturgis were components of the path between Kalamazoo and Fort Wayne, Indiana. The link between Flint and Holly (south of Flint) constituted a segment of the route which was eventually constructed from Saginaw to Toledo.

Alternatives incorrectly accepted.--In examining the incorrectly accepted alternatives (Map 25), that is, links which the model predicted but which were not actually constructed between 1860 and 1870, it is apparent that several of the errors may have arisen from the slowness of the entrepreneurs to perceive the profitability of certain of the alternatives. Three misclassified potential links were actually accepted as alternatives between 1870 and 1880, and one in the 1890's.

Another reason for several of the errors is the existence of superior routes running parallel to the alternatives. The model assumes that the decisions were absolute--either a link was accepted or it was rejected, independent of all other alternatives. However, in some instances relative decisions were made, that is, the best alternative was chosen. As the network was extended northwestward from Charlotte (located southwest of Lansing) the decision maker


SOUTHERN MICHIGAN
RAILROAD NETWORK
ALTERNATIVES INCORRECTLY ACCEPTED
1860-1870
POPULATION 1860
MILES
SAGINAW
GRAND RAPIDS
FLINT
PORT HURON
LANSING
PONTIAC
BATTLE CREEK
DETROIT
KALAMAZOO
MARSHALL
JACKSON
ANN ARBOR
YPSILANTI
MONROE
HILLSDALE
ADRIAN
MICHIGAN CITY
SOUTH BEND
TOLEDO
LA PORTE
N

MAP 25

was faced with three alternatives, all met the minimum criteria necessary to be accepted. The alternative running between Charlotte and Grand Rapids, which had the highest value, was chosen, while the potential links from Charlotte to Ionia and Lowell were rejected.

The same situation was faced by the entrepreneurs extending the network west from Bay City and Saginaw to Farwell. The alternatives extending westward from both Bay City and Saginaw met the minimum requirements, but if both were constructed there would have been a duplication of services; therefore, the decision maker chose the alternative from Saginaw to Farwell which had the best combination of attributes. Parallel alternatives also occurred south from Saginaw. The link between Saginaw and Flushing was only a few miles west of the potential link between Flint and Saginaw, which had a superior combination of characteristics.

A slightly different condition occurred at Kalamazoo. The potential link between Kalamazoo and Paw Paw had characteristics indicating that it would have been accepted; however, it paralleled a previously established link between Kalamazoo and Lawton (four miles southeast of Paw Paw). Therefore instead of building the twenty mile link from Kalamazoo to Paw Paw, the entrepreneur chose to connect Paw Paw to Lawton. Similarly the alternative connecting Battle Creek with Plainwell (north of Kalamazoo) was paralleled by an existing slightly longer route which ran from Battle Creek to Kalamazoo to Plainwell.

An example of a modified delta-wye transformation provides an explanation for the rejection of the alternative between Eaton Rapids (south of Lansing) and Jackson. The entrepreneurs instead chose the link that connected Eaton Rapids to Leslie, which was on an existing route between Lansing and Jackson. The total length of construction was reduced, while the distance between the two cities was not substantially increased.

1870-1880

Just as in the previous decade, between 1870 and 1880 lumber was still the major commodity carried by the railroads; thus, the potential locations away from competition were the most attractive (see Table 4).[4] Locally generated interaction, therefore, is again the most important of the three factors in the decision making process.

The other surrogates for local interaction, the size of the centers connected by the alternative (variable 3) and the length of the potential link (variable 1) did not have

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[4]This avoidance of competition is indicated by the variables ranking first, second, and eight in contribution to the discriminant function (see Table 4)--the percentage of urban centers connected to the network within ten miles of the alternative (variable 5), the number of urban centers connected to the network within ten miles of the alternative (variable 4), and the percentage of the urban centers connected to the network within thirty miles of the potential link (variable 8).

TABLE 4.--Rank and standardized weights of the discriminant function for the growth of the railroad network of southern Michigan from 1870 to 1880[a]

	Variable Number and Name	Standardized Weight	Rank
1.	Length of the alternative...........	.185	9
2.	Population of the larger node.......	. . .[b]	.
3.	Population of the smaller node......	-.458	3
4.	Number of urban centers connected to the network within ten miles of the alternative.........................	-.561	2
5.	Percentage of urban centers connected to the network within ten miles of the alternative..................	-.610	1
6.	Number of urban centers connected to the network within twenty miles of the alternative..................	. . .	.
7.	Percentage of urban centers connected to the network within twenty miles of the alternative............	. . .	.
8.	Number of urban centers connected to the network within thirty miles of the alternative..................	. . .	.
9.	Percentage of urban centers connected to the network within thirty miles of the alternative............	-.194	8
10.	Number of connections to the smaller node.............................	. . .	.
11.	Number of connections to the larger node.............................	. . .	.
12.[c]	Distance to the nearest major urban-economic center.....................	. . .	.
13.	Distance to the second nearest major urban-economic center...............	-.048	10

TABLE 4.--Continued

	Variable Number and Name	Standardized Weight	Rank
14.[d]	Distance added to the nearest least cost path by the connection of the node closer to the path.............	. . .	.
15.	Distance added to the nearest least cost path by the alternative given the initial connection of the node closer to the path..................	.039	11
16.	Distance added to the nearest least cost path by the alternative given the initial connection of the node farther from the path...............	-.360	4
17.	Population of the node closer to the path................................	. . .	.
18.	Population of the node farther from the path............................	.358	5
19.	Alternative north of Bay City.......	-.223	7
20.	Distance to the nearest urban center connected to the network............	-.300	6

[a]The mean score for the alternatives rejected was -1.225, for the alternatives accepted -.730.

[b]The variables with standardized weight less than .1 or with high correlations with several other variables were dropped from the analysis, and the function was recalculated.

[c]The major urban-economic centers were defined as the thirty largest cities.

[d]The least cost paths were defined as the routes between the thirty largest cities.

an influence on the link location decisions; for the longer alternatives were chosen over the shorter ones, and the potential links connecting smaller settlements were selected over those linking larger urban centers. The lack of importance of these attributes in location decisions indicates they were not related to the entrepreneurs' economic motives: to build their railroads into the less developed areas where the links were longer and the nodes smaller, but more importantly where the chances of capturing large amounts of lumber trade were the greatest.

The path effect was of some importance in the decision making process, but again as in the 1860 and 1870 decade there was no trade-off between nodal size and the distance added to the nearest least cost path.[5] However, it is still possible to make some inferences about the behavior of the decision makers. First, when an alternative would cause any divergence from the least cost path, those choices which linked larger centers were preferred (variable 18, rank 5). Secondly, at any given point along a route, the goal was to minimize any further variations from the least cost path being constructed (variable 16, rank 4).

A trade-off could be envisioned between the distance

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[5]The two surrogates for the path effect which are of most importance in differentiating between the two groups of alternatives are 1) the distance added to the nearest least cost path by the alternative, given the initial connection of the node farther from the path (variable 16, rank 4) and 2) the population of the node farther from the least cost path (variable 18, rank 5).

added to the path and the number of competitive nodes. All other things being equal, the entrepreneurs would have been willing to extend the length of the path six miles to reduce the number of competitive nodes by one.

Once more the potential for connection to the network had an important influence on the location decisions. The greater the distance from the alternative to the network, the less likely the potential link was accepted (variable 20, rank 6).

Land grants, which were used by the government to stimulate the expansion of the railroad into the northern part of the state,[6] were not a significant influence on the location decisions.[7] Rather, _ceteris paribus_, there was a preference for alternatives south of Bay City, just the opposite of what would be expected if land grants were important.

Only 69 percent of all of the decisions are correctly duplicated for this period. Seventy-one percent of the alternatives rejected and 65 percent of the links accepted (Map 26) were actually predicted, for an average of 68 percent.

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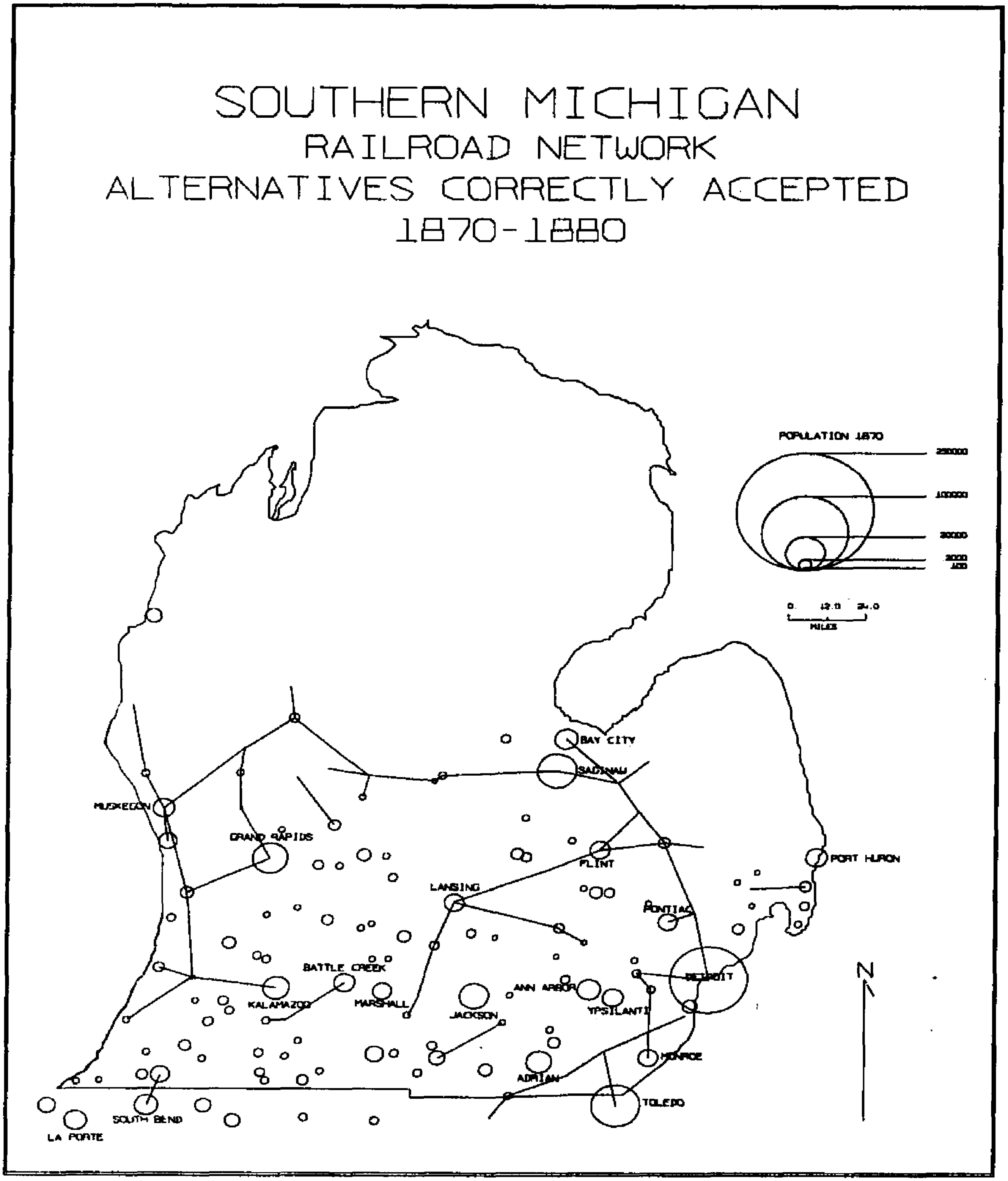
[6]Willis F. Dunbar, _Michigan: A History of the Wolverine State_ (Grand Rapids, Michigan: William B. Eeerduran Publishing Co., 1965), pp. 485-286; Paul W. Ivey, _The Pere Marquette Railroad Company_ (Lansing, Michigan: Michigan Historical Commission, 1919), p. 217.

[7]To take into consideration the influence of land grants on location decisions variable 19 was constructed; alternatives north of Bay City were given a value of one, those south zero.

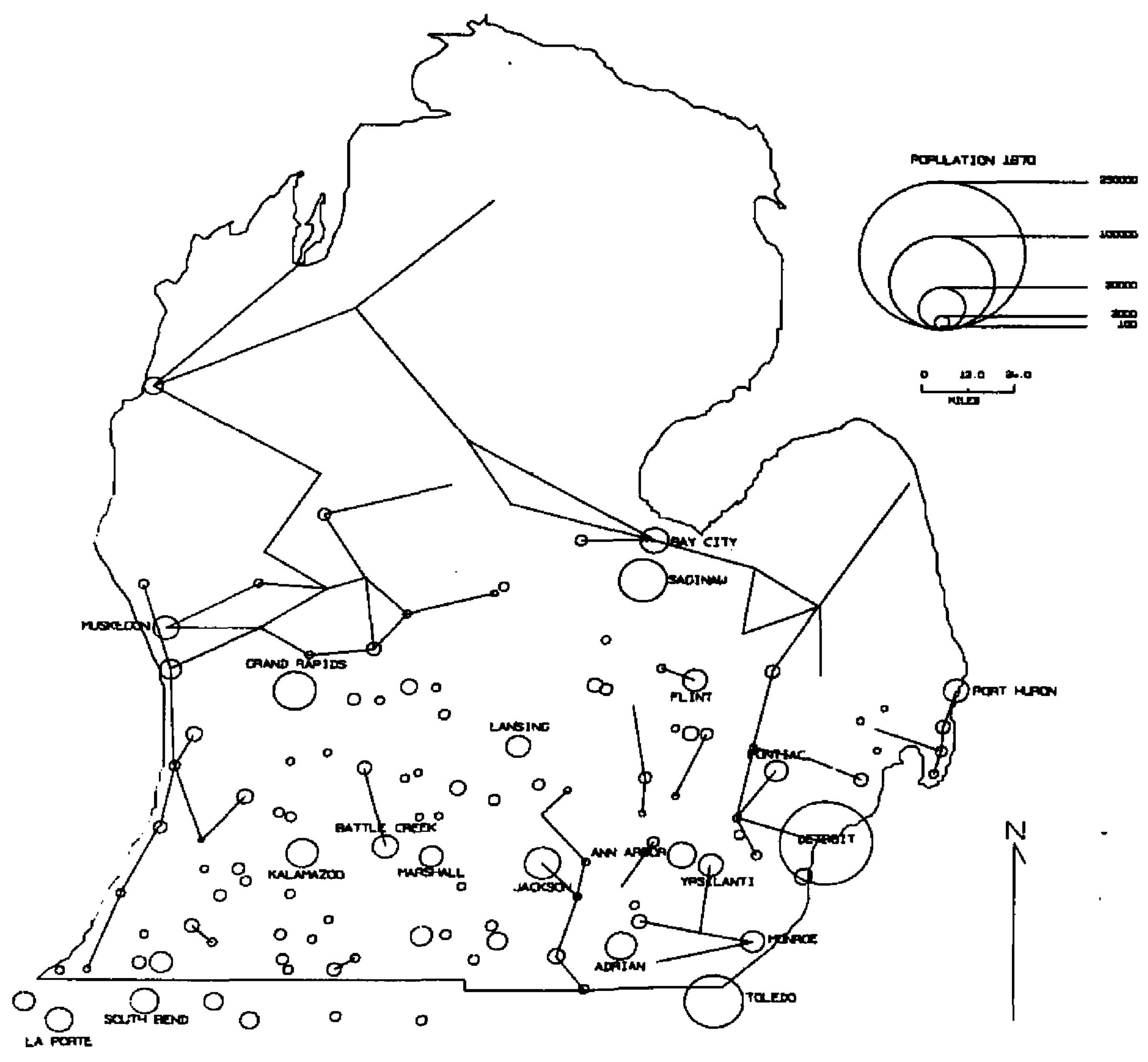

SOUTHERN MICHIGAN
RAILROAD NETWORK
ALTERNATIVES CORRECTLY ACCEPTED
1870-1880
POPULATION 1870
MILES
N
BAY CITY
SAGINAW
MUSKEGON
GRAND RAPIDS
FLINT
PORT HURON
LANSING
PONTIAC
BATTLE CREEK
DETROIT
KALAMAZOO
MARSHALL
JACKSON
ANN ARBOR
YPSILANTI
MONROE
ADRIAN
TOLEDO
SOUTH BEND
LA PORTE

MAP 26

Alternatives incorrectly accepted.--There were 68 alternatives accepted by the model but not built (Map 27); twelve of these alternatives were built at a later date. The existence of routes paralleling the alternatives provides an explanation for several of the other misclassifications. The entrepreneurs would not accept alternatives which would produce duplication in the network; that is, when an existing multiple linked path already connected the two centers joined by the alternative. This type of error accounts for twenty of the alternatives misclassified. The same explanation at a different level of generalization applies to the situation along the southern coast of Lake Michigan, where six alternatives together form a path which parallels an existing route farther from the coast.

The prediction of the acceptance of alternatives paralleling existing links points up one of the deficiencies of the model: it does not explicitly take into consideration the possibility of duplicate facilities already existing. Similarly each alternative is considered independently of the links that were accepted during the period; there is, therefore, a tendency for the model in some of the more isolated areas to over predict the number of links accepted, which is contradictory to the conditions originally leading to the selection of the alternatives. Thus while one or two of the best alternatives should have been selected, all were accepted by the model. Several of these errors occurred

SOUTHERN MICHIGAN
RAILROAD NETWORK
ALTERNATIVES INCORRECTLY ACCEPTED
1870-1880



MAP 27

north of Grand Rapids, in the southeastern quarter of the state, and in the thumb area.

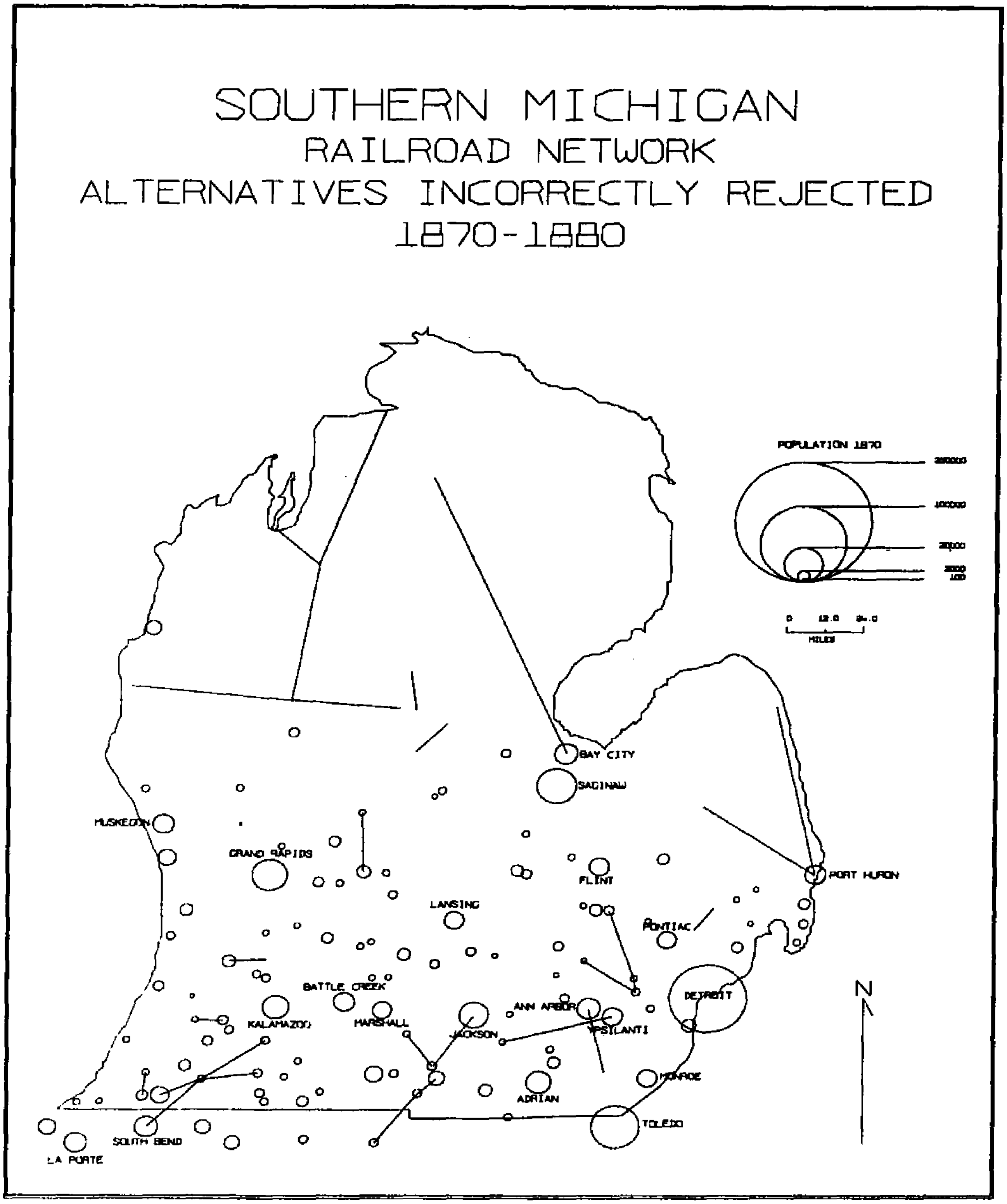
Alternatives incorrectly rejected.--Several of the incorrectly rejected alternatives were parts of intercity routes (see Map 28). The segment from Holly to Plymouth (west of Detroit) was a section of a route running from Saginaw to Monroe, constructed to provide an outlet to the south for lumber for the Pere Marquette Railroad.[8] The link between Dundee and Ann Arbor formed part of the Ann Arbor Railroad that eventually ran between Toledo and Frankfort. The link between Bay City and Gaylord was the first section of a railroad from Bay City to Mackinaw City. The links in the northwestern portion of the state were built for a similar purpose to connect Grand Rapids to Mackinaw City and Traverse City.

Five of the remaining links were constructed as part of the Grand Trunk Railroad's expansion program aimed at making Chicago the western terminus of the railroad.

Inconsistances in the Decision Making Process

The largest expansion of the railroad network took place between 1870 and 1880. The great growth appears to have produced many inconsistances in the decision making process as conceived in this research. Many of the links incorrectly rejected by the model were among the first to be

[8]Ivey, Pere Marquette Railroad, p. 218.


SOUTHERN MICHIGAN
RAILROAD NETWORK
ALTERNATIVES INCORRECTLY REJECTED
1870-1880
POPULATION 1870
MILES
N
BAY CITY
SAGINAW
MUSKEGON
GRAND RAPIDS
FLINT
PORT HURON
LANSING
PONTIAC
DETROIT
BATTLE CREEK
ANN ARBOR
KALAMAZOO
MARSHALL
JACKSON
YPSILANTI
MONROE
ADRIAN
TOLEDO
SOUTH BEND
LA PORTE

MAP 28

abandoned. In addition several of the railroads that built these links had constant financial problems which in part could be related to poor location decisions. For example, the Pere Marquette's route from Saginaw to Ludington, the latter half of which was not predicted by the model, did not prove to be very profitable and the expected traffic over the line did not materialize.[9] The same was true for the two links built north from Port Huron by the Pere Marquette Railroad, also not predicted by the model: "these lines did not prove so profitable as expected."[10] Thus this period was characterized by a number of poor location decisions. Many entrepreneurs made overly optimistic assessments of the future profitability of the alternatives.

1880-1890

The path effect is the most important influence on the location decisions for the decade from 1880-1890 (see Table 5).[11] The alternatives farther from the least cost

[9] Ibid., p. 221.

[10] Ibid., p. 227.

[11] Surrogates for the path effect rank first, third, and fourth in contributing to the discriminant between the two groups of alternatives. The three variables are 1) the distance added to the nearest least-cost path by the connection of the node closer to the path (variable 14), 2) the distance added to the nearest least-cost path by the alternative, given the initial connection of the node farther from the path (variable 16), and 3) the distance added to the nearest least cost path by the alternative, given the initial connection of the node closer to the path (variable 15).

TABLE 5.--Rank and standardized weights of the discriminant function for the growth of the railroad network of southern Michigan from 1880 to 1890[a]

	Variable Number and Name	Standardized Weight	Rank
1.	Length of the alternative...........	.219	5
2.	Population of the larger node.......	.209	7
3.	Population of the smaller node......	.119	13
4.	Number of urban centers connected to the network within ten miles of the alternative.........................	. . .[b]	.
5.	Percentage of urban centers connected to the network within ten miles of the alternative............	. . .	.
6.	Number of urban centers connected to the network within twenty miles of the alternative.....................	. . .	.
7.	Percentage of urban centers connected to the network within twenty miles of the alternative............	-.148	11
8.	Number of urban centers connected to the network within thirty miles of the alternative.....................	. . .	.
9.	Percentage of urban centers connected to the network within thirty miles of the alternative............	. . .	.
10.	Number of connections to the smaller node................................	-.179	9
11.	Number of connections to the larger node................................	-.184	8
12.[c]	Distance to the nearest major urban-economic center.....................	-.178	10
13.	Distance to the second nearest major urban-economic center...............	-.403	2

TABLE 5.--Continued

	Variable Number and Name	Standardized Weight	Rank
14.[d]	Distance added to the nearest least cost path by the connection of the node closer to the path............	.564	1
15.	Distance added to the nearest least cost path by the alternative given the initial connection of the node closer to the path.................	-.339	4
16.	Distance added to the nearest least cost path by the alternative given the initial connection of the node farther from the path..............	-.341	3
17.	Population of the node closer to the path...........................	.209	7
18.	Population of the node farther from the path...........................	.123	12
19.	Alternative north of Bay City......	.217	6
20.	Distance to the nearest urban center connected to the network....	.047	14

[a]The mean score for the group of alternatives rejected was -1.906, for the group of alternatives accepted -1.332.

[b]The variables with standardized weights less than .1 or with high correlations with several other variables were dropped from the analysis, and the function was recalculated.

[c]The major urban-economic centers were defined as the thirty largest cities.

[d]The least cost paths were defined as the routes between the thirty largest cities.

paths were preferred over the nearer ones (see variable 14). These choices were not illogical, for in 1880 the network had fairly well established direct connection between the major economic centers, so the alternative lying near the existing primary routes would seemingly be the least attractive. While there was this tendency to avoid competition,[12] there was also preference for the potential links adding the smallest distance to the least cost path (see variables 15 and 16). Routes paralleling, but away from, the major inter-city routes were favored.

An apparent trade-off between the size of the nodes connected and the distance added to the least cost paths existed during the 1880's, although the differences in the population of the urban centers (variable 17, rank 7; variable 18, rank 12) were not as important as the variations in the distance. Other things being equal, an entrepreneur would have been willing to add one mile to an intercity route for an increase in the nodal population of approximately 242.[13]

Location decisions were also significantly influenced

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[12]It is again apparent that the models are deficient in that they do not explicitly take into consideration the locations of competitive routes.

[13]Ceteris paribus, the decision makers would add one mile to the least cost path, given the initial connection of the node farther from the path, for every increase of 282 inhabitants of the node closer to the path. In perceiving the movement from the node closer to the path to the node farther from the path, the entrepreneurs would extend the length of the intercity route one mile for the addition of every 202 persons.

by the field effect during this decade. Alternatives closer to the second nearest major urban-economic center were preferred over those more isolated (variable 13, rank 2). The distance to the nearest major city was comparatively unimportant factor (variable 12, rank 10). A potential link relatively close to the second nearest city most likely would have been situated in the area between two major centers and presumably would carry greater amounts of traffic than alternatives near only one urban-economic center.

During this period there was a tendency for the decision makers to select the longer alternatives (variable 1, rank 5). The length of a potential link, therefore, did not have an influence on the location decisions. The propensity to choose the longer links can be interpreted as an avoidance of competition, since the shortest alternatives were in the densely settled area which were the first to be served by the railroad. The choice of longer routes does not mean that locally generated interaction was totally unimportant in the decision making process. The entrepreneurs preferred alternatives joining larger nodes (variable 2, rank 7; variable 3, rank 13) and those where there were fewer competitive nodes (variable 7, rank 11).

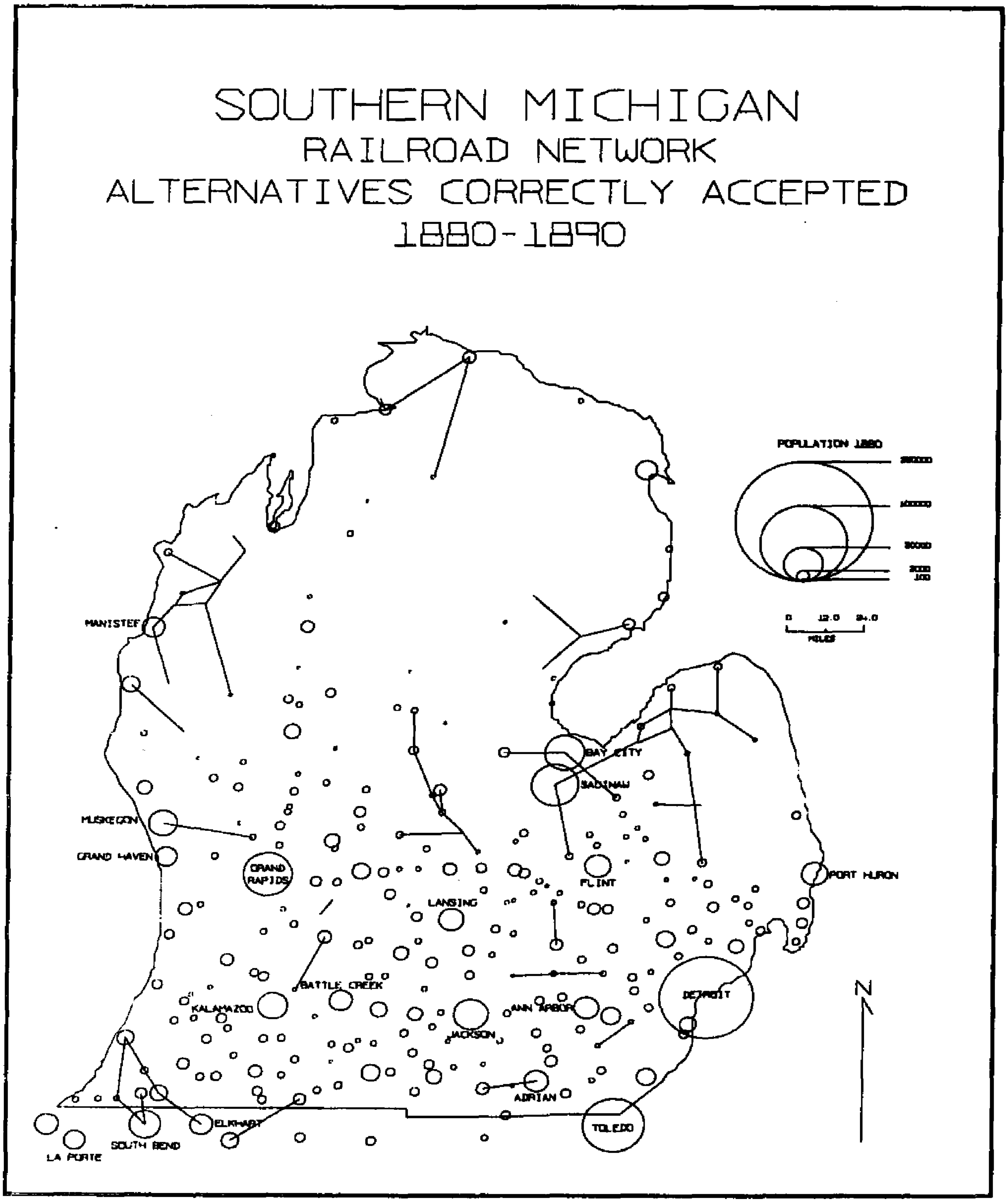
During this period a preference for the alternatives north of Bay City appeared (variable 20, rank 6). Other things being equal, an alternative north of Bay City could have been 28.6 miles farther from the second nearest urban-economic center than a node in the southern part of the state and still would have been equally likely to be constructed.

The number of connections to the two nodes joined by the alternatives (variable 11, rank 8; variable 10, rank 9) had an effect on location decisions. Instead of being indicators of the field effect, these two attributes demonstrate the preference of the entrepreneurs to avoid competition; there was fear of losing traffic to rival railroads linking the nodes.

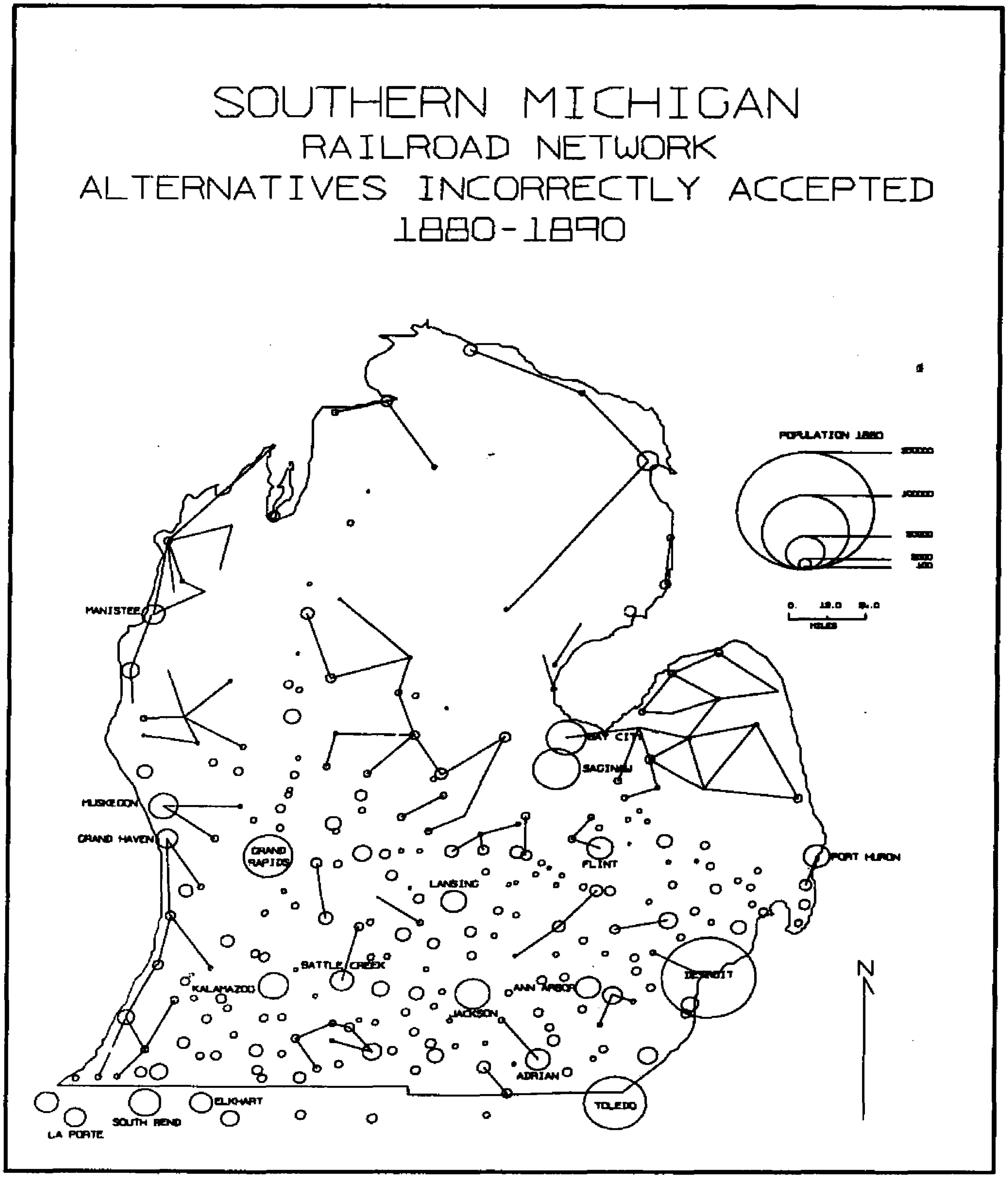
The lack of significance of the distance to the nearest node connected to the network is an indication that the network was sufficiently ubiquitous that no alternative was too far from the network.

The predictability of the model was 73 percent for all of the decisions; however, it was a comparatively low 51 percent for the alternatives accepted (see Map 29). Of the alternatives rejected 78 percent were properly delineated. The average of the latter two figures is 65 percent.

Alternatives incorrectly accepted.--There were 94 alternatives (see Map 30) which were accepted by the model that actually were not constructed between 1880 and 1890; ten of these alternatives were accepted at a later date. The two primary reasons for most of the remaining errors were the same as in the previous period. First, 37 of the alternatives represented duplications of existing facilities. Second, in most of the remaining cases the model over predicted


SOUTHERN MICHIGAN
RAILROAD NETWORK
ALTERNATIVES CORRECTLY ACCEPTED
1880-1890
POPULATION 1880
MILES
MANISTEE
MUSKEGON
GRAND HAVEN
GRAND RAPIDS
BAY CITY
SAGINAW
FLINT
LANSING
PORT HURON
BATTLE CREEK
KALAMAZOO
ANN ARBOR
JACKSON
DETROIT
ADRIAN
TOLEDO
ELKHART
SOUTH BEND
LA PORTE
N

MAP 29


SOUTHERN MICHIGAN
RAILROAD NETWORK
ALTERNATIVES INCORRECTLY ACCEPTED
1880-1890
POPULATION 1880
MANISTEE
MUSKEGON
GRAND HAVEN
GRAND RAPIDS
LANSING
FLINT
BAY CITY
SAGINAW
PORT HURON
BATTLE CREEK
KALAMAZOO
JACKSON
ANN ARBOR
DETROIT
ADRIAN
TOLEDO
ELKHART
SOUTH BEND
LA PORTE
N

MAP 30

the more isolated areas, especially in the thumb area and in the region north of Grand Rapids.

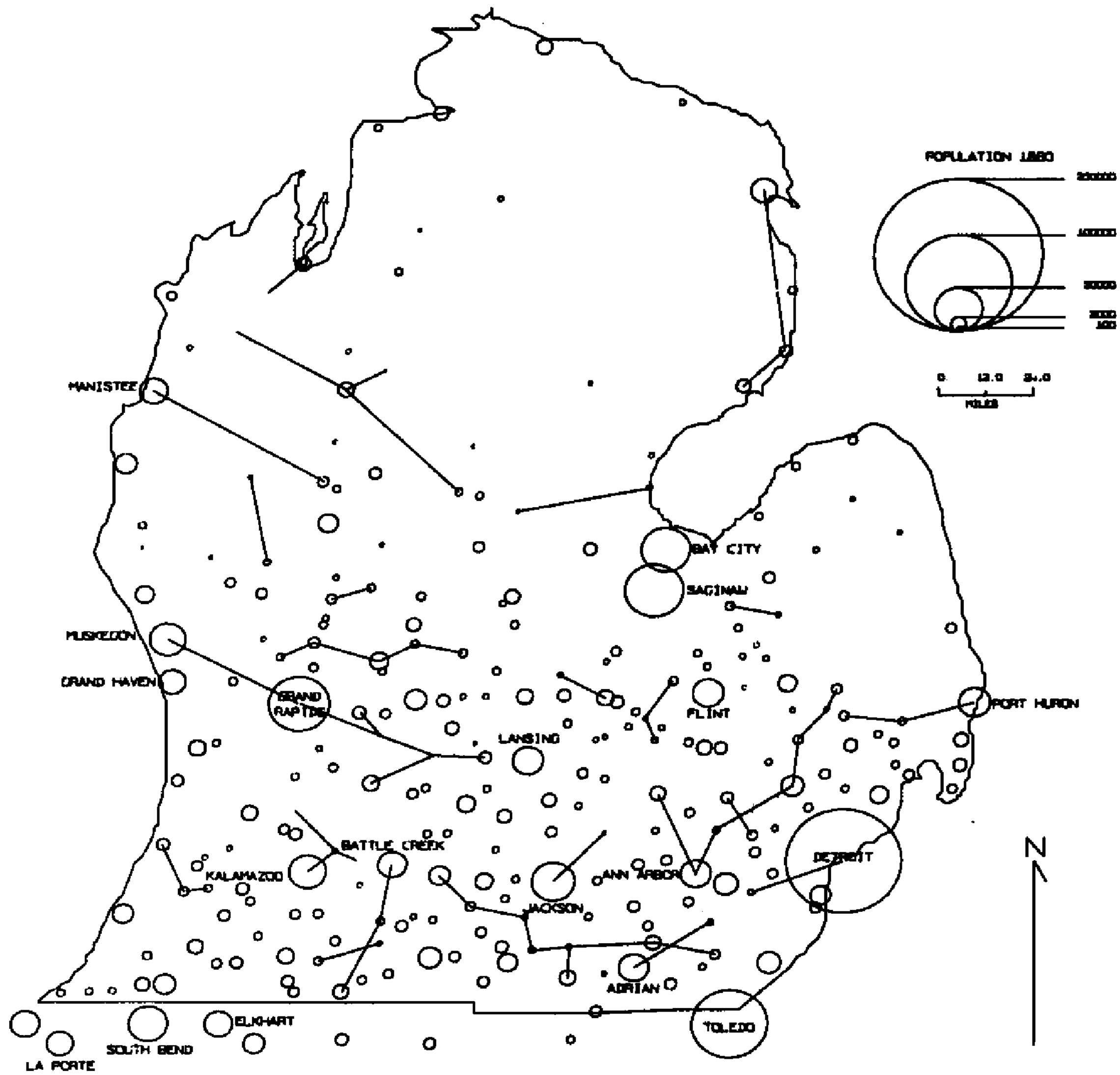
Alternatives incorrectly rejected.--The 1880-1890 period was again one characterized by inconsistencies in the decision making process as conceived in this research. Sixteen of the 51 alternatives (see Map 31) misclassified were abandoned within the next sixty years. The series of links running from Marshall (east of Battle Creek) to Dundee (east of Adrian) was abandoned between 1920 and 1930. The same is true for the two links running south from Battle Creek. Seventeen of the remaining links, forming parts of intercity routes constructed by the major railroad companies, indicate that the variables used as surrogates for the path effect do not properly measure the influence of this factor.

1890-1900 and 1900-1910

The models for 1890-1900 and 1900-1910 predict 80 and 83 percent of the entrepreneural decisions respectively; however, in the northern part of the study area, where most of the growth of the network was concentrated, they do not differentiate between the links actually constructed and those rejected by the decision makers. To alleviate this deficiency a second set of models, using only alternatives north of Bay City, predict about 60 percent of the decisions.

It can be concluded either the entrepreneurs acted irrationally, basing their decisions on overly optimistic estimates of future profitability, or the attributes of the

SOUTHERN MICHIGAN
RAILROAD NETWORK
ALTERNATIVES INCORRECTLY REJECTED
1880-1890



MAP 31

alternatives used in the model are not surrogates for the actual characteristics influencing location decisions.

1910-1920

The field effect was a significant factor in the decision making process during the 1910-1920 period. The smaller the distance to the nearest major urban-economic center (variable 12, rank 1), the more preferred an alternative (see Table 6). The propensity to select potential links greater distances from the second nearest major city (variable 13, rank 2) does not denote economic motivation, but a trend toward the choice of peripheral locations away from competition. The preference for link locations away from the least cost routes--and competition--over those closer to the paths (variable 14, rank 6) supports this interpretation. Along with the avoidance of the least cost lines, there was a tendency to select alternatives which paralleled the routes (variable 15, rank 4), indicating the path effect also had an influence on location decisions.

There was a trade-off between the size of the nodes (variable 17, rank 9) and the distance added to the least cost path. Other things being equal, an entrepreneur would have been willing to extend the length of the path one mile for every increase in the nodal population of 3100, a figure substantially higher than the 242 for the 1880-1890 period, indicating a reduction of the relative importance of the size of the nodes.

TABLE 6.--Rank and standardized weights of the discriminant function for the growth of the railroad network of southern Michigan from 1910-1920[a]

	Variable Number and Name	Standardized Weight	Rank
1.	Length of the alternative...........	-.395	3
2.	Population of the larger node.......	.188	9
3.	Population of the smaller node......	.151	10
4.	Number of urban centers connected to the network within ten miles of the alternative.....................	. . .[b]	.
5.	Percentage of urban centers connected to the network within ten miles of the alternative............	-.319	5
6.	Number of urban centers connected to the network within twenty miles of the alternative..................	-.117	13
7.	Percentage of urban centers connected to the network within twenty miles of the alternative............	-.121	12
8.	Number of urban centers connected to the network within thirty miles of the alternatives.................	. . .	.
9.	Percentage of urban centers connected to the network within thirty miles of the alternative.....	. . .	.
10.	Number of connections to the smaller node.......................	. . .	.
11.	Number of connections to the larger node..............................	. . .	.
12.[c]	Distance to the nearest major urban-economic center....................	-.457	1
13.	Distance to the second nearest major urban-economic center...............	.404	2

TABLE 6.--Continued

	Variable Number and Name	Standardized Weight	Rank
14.[d]	Distance added to the nearest least cost path by the connection of the node closer to the path.............	.229	6
15.	Distance added to the nearest least cost path by the alternative given the initial connection of the node closer to the path..................	-.334	4
16.	Distance added to the nearest least cost path by the alternative given the initial connection of the node farther from the path...............	-.226	7
17.	Population of the node closer to the path................................	.118	9
18.	Population of the node farther from the path............................	. . .	.
19.	Alternative north of Bay City.......	-.202	8
20.	Distance to the nearest urban center connected to the network.....	. . .	.

[a]The mean score for the group of alternatives rejected was -1.399, for the group of alternatives accepted -.788.

[b]The variables with standardized weights less than .1 or with high correlations with several other variables were dropped from the analysis, and the function was recalculated.

[c]The major urban-economic centers were defined as the twenty largest cities.

[d]The least cost paths were defined as the routes between the twenty largest cities.

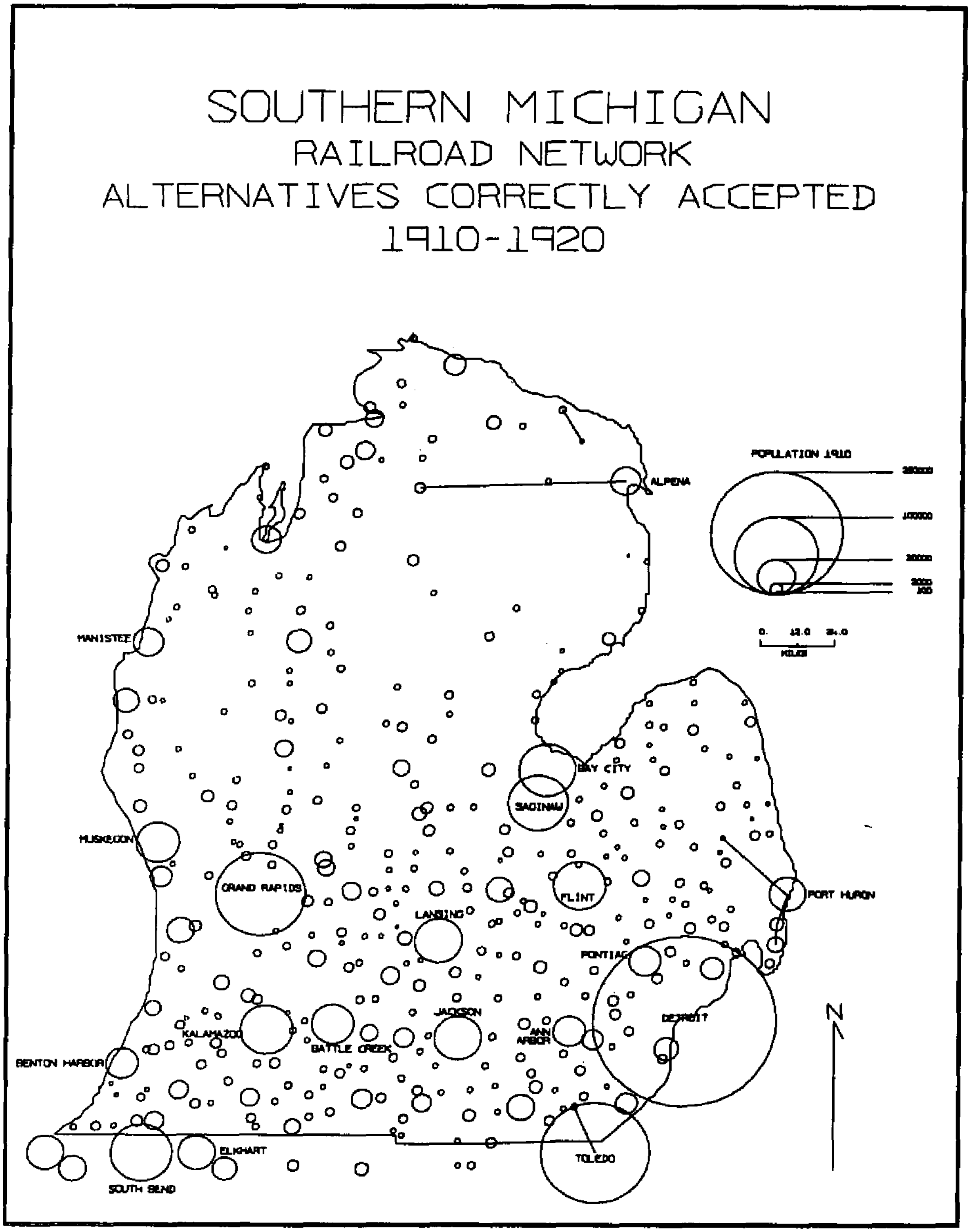
The location decisions during this period were also affected by the potential of an alternative to generate local traffic. The lower the percentage of urban centers connected to the network within ten miles of the alternative (variable 5, rank 5), the more likely a link location was chosen. This preference indicates the entrepreneurs again favored locations with the least amount of competition.

Other surrogates for local interaction were also significant. The shorter alternatives were elected over the longer ones (variable 1, rank 3). The larger the nodes connected by the potential link (variable 2, rank 9; variable 3, rank 10), the more probable the alternatives were constructed, although size was comparatively less important.

The model for this period forecasts the alternatives rejected significantly better than the previous models; over 91 percent are correctly identified. But the model is a poor predictor of the alternatives accepted; only 55 percent are chosen properly (see Map 32). These two figures yield an average of 73 percent.

Alternatives incorrectly rejected.--In four out of the five cases of misclassification there appeared to be no reasonable explanation. The fifth alternative formed part of a path between Detroit and Toledo.

Alternatives incorrectly accepted.--This set of alternatives was typified by the existence of parallel routes, as was the case for 30 of the 54 alternatives misclassified


SOUTHERN MICHIGAN
RAILROAD NETWORK
ALTERNATIVES CORRECTLY ACCEPTED
1910-1920
POPULATION 1910
ALPENA
MANISTEE
BAY CITY
SAGINAW
MUSKEGON
GRAND RAPIDS
FLINT
PORT HURON
LANSING
PONTIAC
KALAMAZOO
BATTLE CREEK
JACKSON
ANN ARBOR
DETROIT
BENTON HARBOR
ELKHART
SOUTH BEND
TOLEDO
N

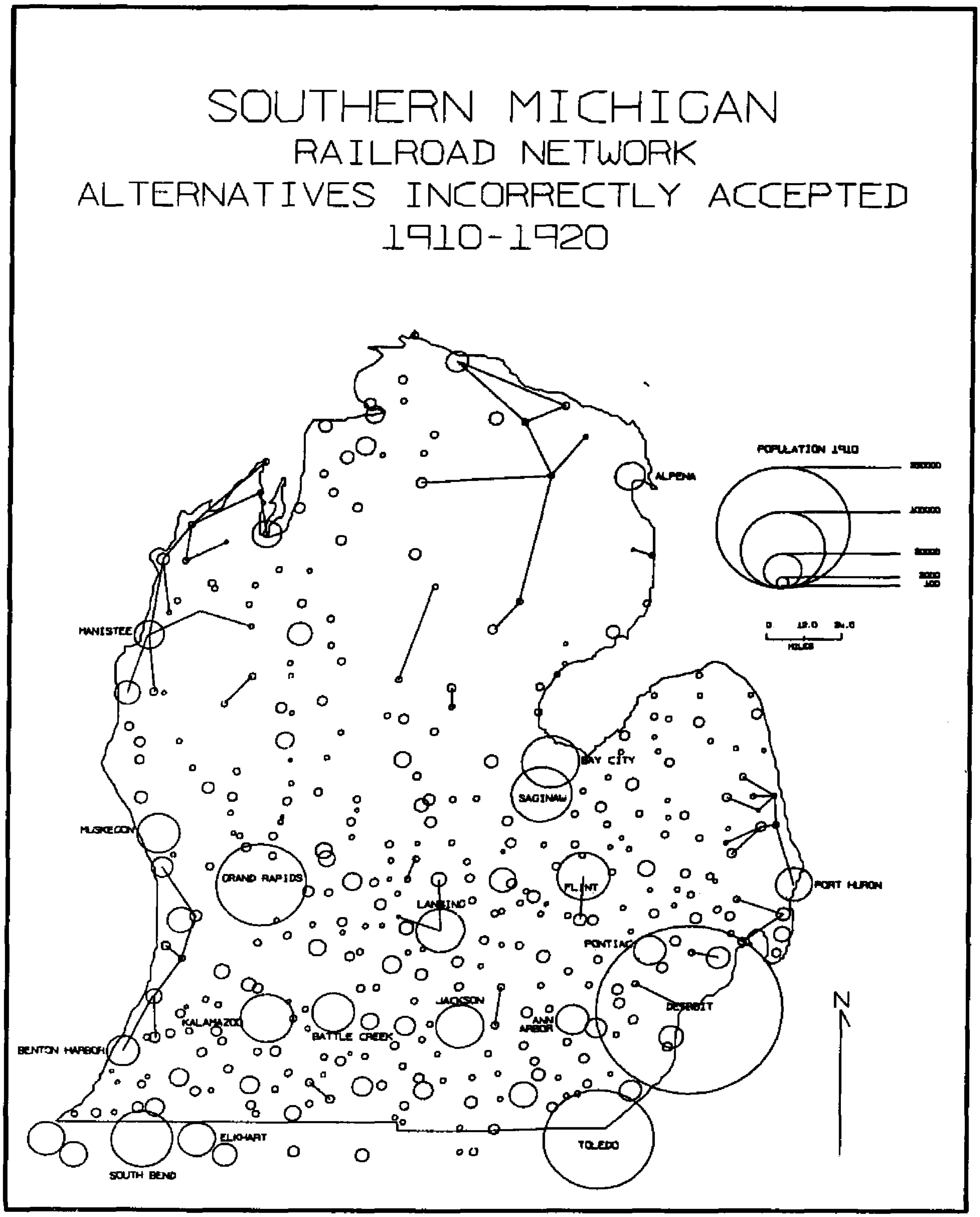
MAP 32

(see Map 33). Errors occurred with the presence of duplicate routes as well as individual links. The two groups of alternatives along the southern and northern coast of Lake Michigan are a repetition of existing facilities. There is no apparent explanation for the remaining errors.

Changing Location Preferences: 1860-1920

During the first two decades, 1860-1880, the potential traffic generated by the two nodes that would be served by the potential link (local interaction) was the most important influence in the decision making process; however, the entrepreneurs did not show preference for the shorter alternatives connecting the larger nodes, but rather for the potential links in areas with the fewest number and lowest percentage of competitive nodes. The potential for local interaction was less prominent in the decision making process after 1880, but it was still of significance.

The proximity of alternatives to the major intercity routes (path effect) was the most important influence on location decisions in the decade from 1880 to 1890, contrasted to its secondary effect earlier. There was a propensity to choose routes paralleling the least cost path joining the major urban-economic centers. One anomaly existed in the hypothesized preferences: the alternatives farther from the least cost lines were selected over those nearer the routes. This behavior is an indication of the avoidance by entrepreneurs


SOUTHERN MICHIGAN
RAILROAD NETWORK
ALTERNATIVES INCORRECTLY ACCEPTED
1910-1920
POPULATION 1910
MILES
ALPENA
MANISTEE
BAY CITY
SAGINAW
MUSKEGON
GRAND RAPIDS
LANSING
FLINT
PORT HURON
PONTIAC
DETROIT
KALAMAZOO
BATTLE CREEK
JACKSON
ANN ARBOR
BENTON HARBOR
ELKHART
SOUTH BEND
TOLEDO
N

MAP 33

of existing competitive lines. After 1880 it is possible to identify a trade-off between the size of the nodes and the distance added to the paths. Other things being equal, a route would have been extended one additional mile for each increase of 242 inhabitants. The population figure increased to 3100 for 1910.

Propinquity to major urban-economic centers (field effect) was not of consistent importance in the decision making process, and overall it was the least significant of the factors influencing location decisions. For the decade between 1870 and 1880 proximity to important cities had a negligible impact on the link locations. The 1910 to 1920 period was the only one in which adjacency to major urban centers had the greatest effect on location selection.

One factor not included in the models, having a consistently significant influence during all periods, was the location of competition, an element not recognized in previous research. The lack of variables explicitly measuring proximity to competitive links limited the meaningfulness and predictability of the models.

CHAPTER VI

DECLINE OF THE RAILROAD NETWORK OF SOUTHERN MICHIGAN

The purpose of this chapter is to determine how well the decline of the railroad network of southern Michigan can be explained by the three hypothesized factors. The major portion of the decline of the network occurred between 1910 and 1967.[1] A discriminant analysis model is produced for five periods.[2] The two groups of alternatives used in the models are 1) the links abandoned and 2) the links retained in the network. The attributes used to differentiate between the two groups of alternatives are found in Table 1.

1910-1920

The field effect was the most prominent of the three factors in the decision making process during this decade. The links the greatest distance from the two nearest major urban-economic centers (variable 12, rank 5; variable 13,

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[1]The decline of the network actually started in 1890. Three percent of the network was abandoned between 1890 and 1900, and six percent between 1900 and 1910. Models using such a small proportion of the network would not be significant, therefore these two decades are dropped from the analysis.

[2]The period used are as follows: 1910-1920, 1920-1930, 1930-1942, 1942-1952, 1952-1967.

rank 2) were the first to be abandoned (see Table 7). There was also a propensity to abandon the links in the areas with a lower concentration of competitive nodes (variable 6, rank 1). Thus the links more centrally located and in the areas of highest nodal density were generally retained in the network by the entrepreneurs.

The amount of locally generated interaction had a secondary influence on the location decisions. The longer links were the first to be abandoned (variable 1, rank 4); similarly the links in areas with a higher proportion of competition (variable 7, rank 6) and those connecting smaller nodes (variable 3, rank 8) were more likely abandoned.

The path effect was of least significant influence on the process of choosing alternatives to be abandoned. The links adding the greatest distances to the least cost paths (variable 16, rank 3) were generally abandoned first.

Using this model it was possible to predict 77 percent of all the decisions. All links abandoned were identified correctly (see Map 14), while 76 percent of the links remaining in the network were properly delineated.

Links incorrectly abandoned.--Of the 119 links which are misclassified (see Map 34), 21 were abandoned before 1967. There are two striking features which characterized the remaining errors. First, there is a boundary problem; the model abandons almost all the links crossing the southern border of the study area. This phenomenon alone accounts

TABLE 7.--Rank and standardized weights of the discriminant function for the decline of the railroad network of southern Michigan from 1910 to 1920[a]

	Variable Number and Name	Standardized Weight	Rank
1.	Length of the link	.225	4
2.	Population of the larger node	. . .[b]	.
3.	Population of the smaller node	-.169	8
4.	Number of urban centers connected to the network within ten miles of the link	. . .	.
5.	Percentage of urban centers connected to the network within ten miles of the link	. . .	.
6.	Number of urban centers connected to the network within twenty miles of the link	-.619	1
7.	Percentage of urban centers connected to the network within twenty miles of the link	.172	6
8.	Number of urban centers connected to the network within thirty miles of the link	. . .	.
9.	Percentage of urban centers connected to the network within thirty miles of the link	. . .	.
10.	Number of connections to the smaller node	. . .	.
11.	Number of connections to the larger node	. . .	.
12.[c]	Distance to the nearest major urban-economic center	.185	5
13.	Distance to the second nearest major urban-economic center	.528	2

TABLE 7.--Continued

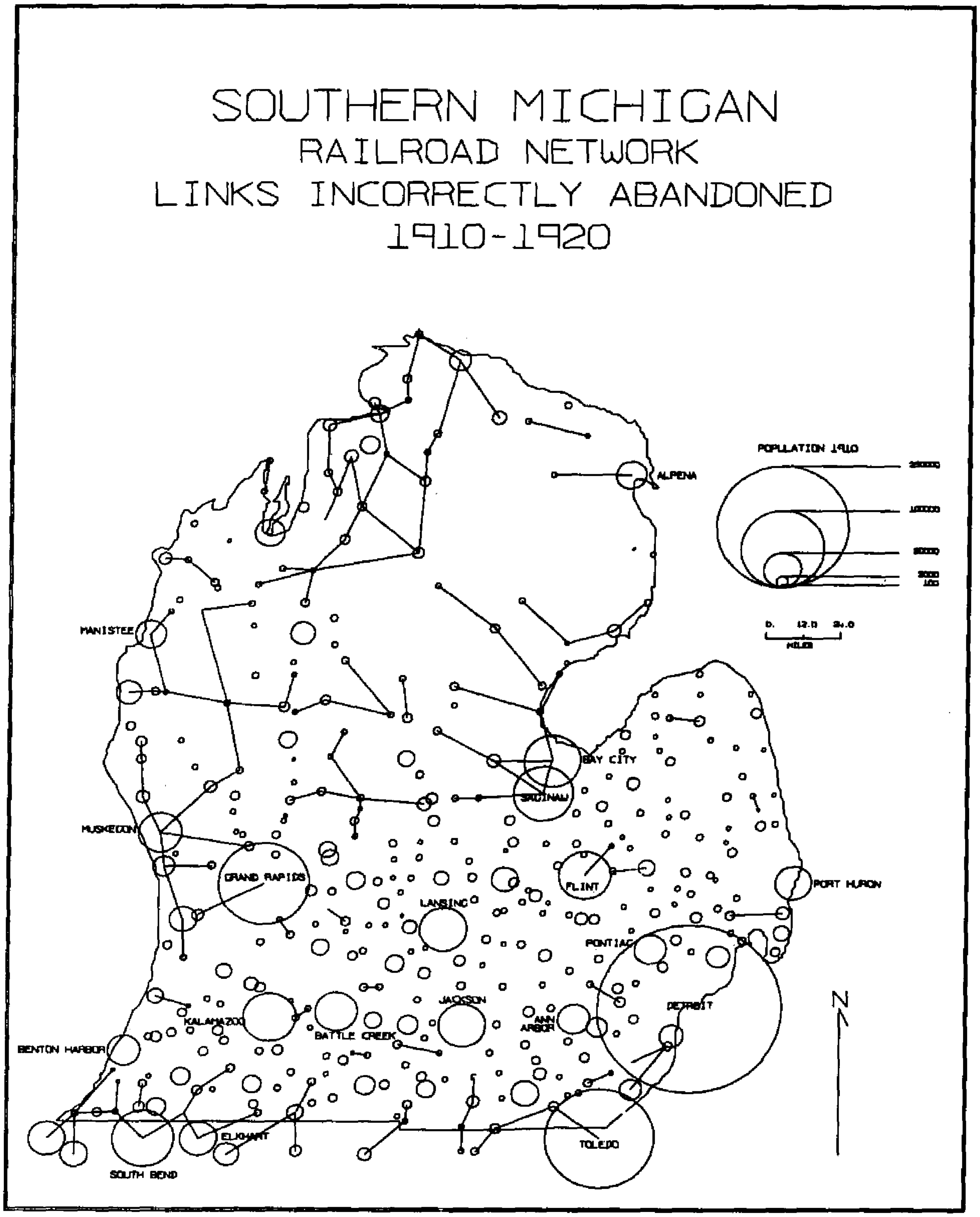
	Variable Number and Name	Standardized Weight	Rank
14.[d]	Distance added to the nearest least cost path by the connection of the node closer to the path............	-.159	9
15.	Distance added to the nearest least cost path by the link given the initial connection of the node closer to the path..................	. . .	.
16.	Distance added to the nearest least cost path by the link given the initial connection of the node farther from the path...............	.370	3
17.	Population of the node closer to the path...........................	. . .	.
18.	Population of the node farther from the path...........................	-.106	10

[a]The mean score for the group of links retained in the network was -.127, for the group of links abandoned .564.

[b]The variables with standardized weights less than .1 or with high correlations with several other variables were dropped from the analysis, and the function was recalculated.

[c]The major urban-economic centers were defined as the fifty largest cities.

[d]The least cost paths were defined as the routes between the fifty largest cities.


SOUTHERN MICHIGAN
RAILROAD NETWORK
LINKS INCORRECTLY ABANDONED
1910-1920
POPULATION 1910
ALPENA
MANISTEE
BAY CITY
SAGINAW
MUSKEGON
GRAND RAPIDS
LANSING
FLINT
PORT HURON
PONTIAC
DETROIT
KALAMAZOO
BATTLE CREEK
JACKSON
ANN ARBOR
BENTON HARBOR
ELKHART
SOUTH BEND
TOLEDO
N

MAP 34

for 21 more errors. The second obvious feature is the over prediction of the northern half of the study area. Seven of the twelve links abandoned were in this area, while a very small proportion of the links remaining in the network were in the same area. So the model differentiated between the links in the north and the south, more than among those abandoned and retained in the network. Thus most of the errors are related to deficiencies in the methodology and not problems of conceptualization.

1920-1930

During this decade the path effect was the factor with the greatest impact on the entrepreneural decisions (see Table 8). The links adding the greatest distance to the least cost paths were the first to be abandoned (variable 16, rank 1; variable 15, rank 2). Also the links farther from the routes were more likely abandoned (variable 14, rank 6).[3]

Similar to the previous period the shorter links (variable 1, rank 3) connecting the larger nodes (variable 3, rank 8) were retained in the network, indicating the potential for locally generated traffic was of secondary

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[3]The attribute making the fourth greatest contribution to the discriminant function is the size of the node farther from the nearest least cost path (variable 18), a surrogate for the path effect. Contrary to what might be expected, the larger the node the more likely the link was abandoned. It can be concluded, therefore, that the size of the nodes did not have an influence on the location decisions.

TABLE 8.--Rank and standardized weights of the discriminant function for the decline of the railroad network of southern Michigan from 1920 to 1930[a]

	Variable Number and Name	Standardized Weight	Rank
1.	Length of the link..................	.459	3
2.	Population of the larger node.......	. . .[b]	.
3.	Population of the smaller node......	-.208	8
4.	Number of urban centers connected to the network within ten miles of the link...........................	. . .	.
5.	Percentage of urban centers connected to the network within ten miles of the link..................	. . .	.
6.	Number of urban centers connected to the network within twenty miles of the link........................	. . .	.
7.	Percentage of urban centers connected to the network within twenty miles of the link..................	. . .	.
8.	Number of urban centers connected to the network within thirty miles of the link........................	. . .	.
9.	Percentage of urban centers connected to the network within thirty miles of the link..................	. . .	.
10.	Number of connections to the smaller node..............................	.234	7
11.	Number of connections to the larger node..............................	-.182	9
12.[c]	Distance to the nearest major urban-economic center...............	. . .	.
13.	Distance to the second nearest major urban-economic center...............	.255	5

TABLE 8.--Continued

	Variable Number and Name	Standardized Weight	Rank
14.[d]	Distance added to the nearest least cost path by the connections of the node closer to the path............	.242	6
15.	Distance added to the nearest least cost path by the link given the initial connection of the node closer to the path..................	.420	2
16.	Distance added to the nearest least cost path by the link given the initial connection of the node farther from the path..............	.536	1
17.	Population of the node closer to the path............................	. . .	.
18.	Population of the node farther from the path............................	.263	4

[a]The mean score for the group of links retained in the network was 4.896, for the group of links abandoned 10.704.

[b]The variables with standardized weights less than .1 or with high correlations with several other variables were dropped from the analysis, and the function was recalculated.

[c]The major urban-economic centers were defined as the ten largest cities.

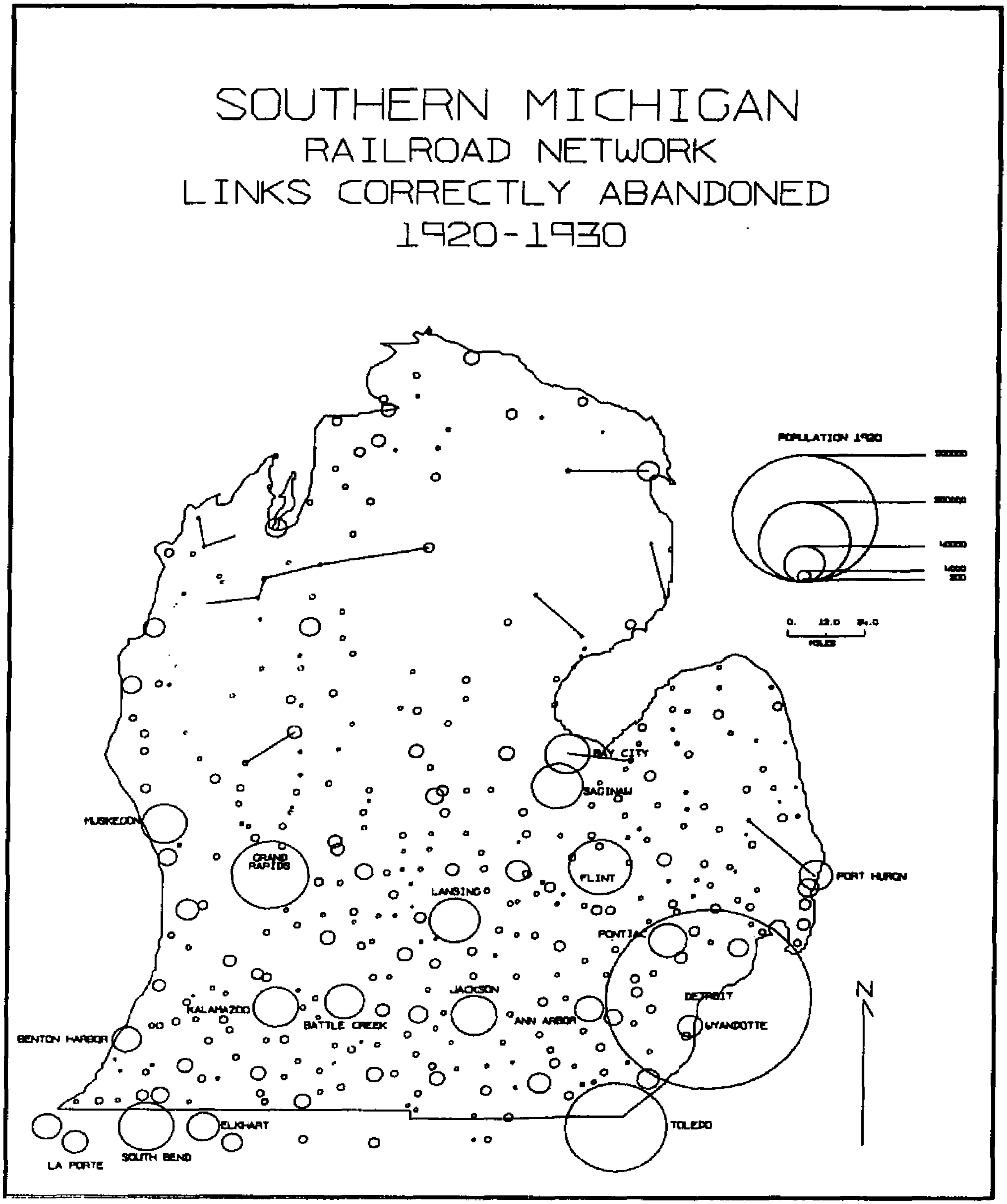
[d]The least cost paths were defined as the routes between the ten largest cities.

importance in making location decisions. The field effect was also of minor significance; the links farthest from the second nearest center had the greatest likelihood of being abandoned (variable 13, rank 5), and the links providing duplicate services to smaller nodes were the least preferred (variable 10, rank 7; variable 11, rank 9).

The model predicted 79 percent of all of the decisions correctly. Of the links retained in the network 79 percent were properly identified, while 80 percent of the links abandoned were correctly predicted (see Map 35).

Links incorrectly retained.--There were only three links that should have been abandoned by the model, but were retained. Two of these links ran south from Benton Harbor to Buchanan, which was north of but not connected to South Bend, Indiana. These two links were paralleled by two routes, one to the east and one to the west, running from Benton Harbor to South Bend. These two links were, therefore, a duplication of the other facilities which had a greater potential for carrying a larger volume of intercity freight. The third link, which joined Caro and Akron (southeast of Bay City), would have been isolated from the remainder of the Detroit and Mackinaw City Railroad, which abandoned all the links it owned south of Bay City.

Links incorrectly abandoned.--Thirteen of the links incorrectly abandoned by the model were dropped from the network after 1930. Most of the remaining errors occurred


SOUTHERN MICHIGAN
RAILROAD NETWORK
LINKS CORRECTLY ABANDONED
1920-1930
POPULATION 1920
MILES
N
MUSKEGON
GRAND RAPIDS
LANSING
FLINT
BAY CITY
SAGINAW
PORT HURON
PONTIAC
DETROIT
WYANDOTTE
KALAMAZOO
BATTLE CREEK
JACKSON
ANN ARBOR
BENTON HARBOR
ELKHART
SOUTH BEND
LA PORTE
TOLEDO

MAP 35

at locations, which were proximal to the nearest urban-economic centers (see Map 36), and therefore, were farther from the second closest large city. The links abandoned in reality tended to be located greater distances from the second nearest major center.[4]

1930-1942

The path effect was the most important factor in the decision making process, just as in the previous decade (see Table 9). The links farthest from the least cost routes had the greatest chance of being abandoned (variable 14, rank 2). Similarly the entrepreneurs abandoned the links adding the largest distances to the least cost paths (variable 16, rank 3; variable 15, rank 4). In addition the routes connecting larger nodes were preferred (variable 18, rank 8). The decision makers would be willing to retain a link if, other things being equal, for every mile it added to the path the population increased by 1420.

The field effect also had a significant impact on location decisions during this period. The greater the distance to the second nearest large city the more likely a link was abandoned (variable 13, rank 1). Likewise, the links providing duplicate services to the smaller nodes were abandoned first (variable 10, rank 5).

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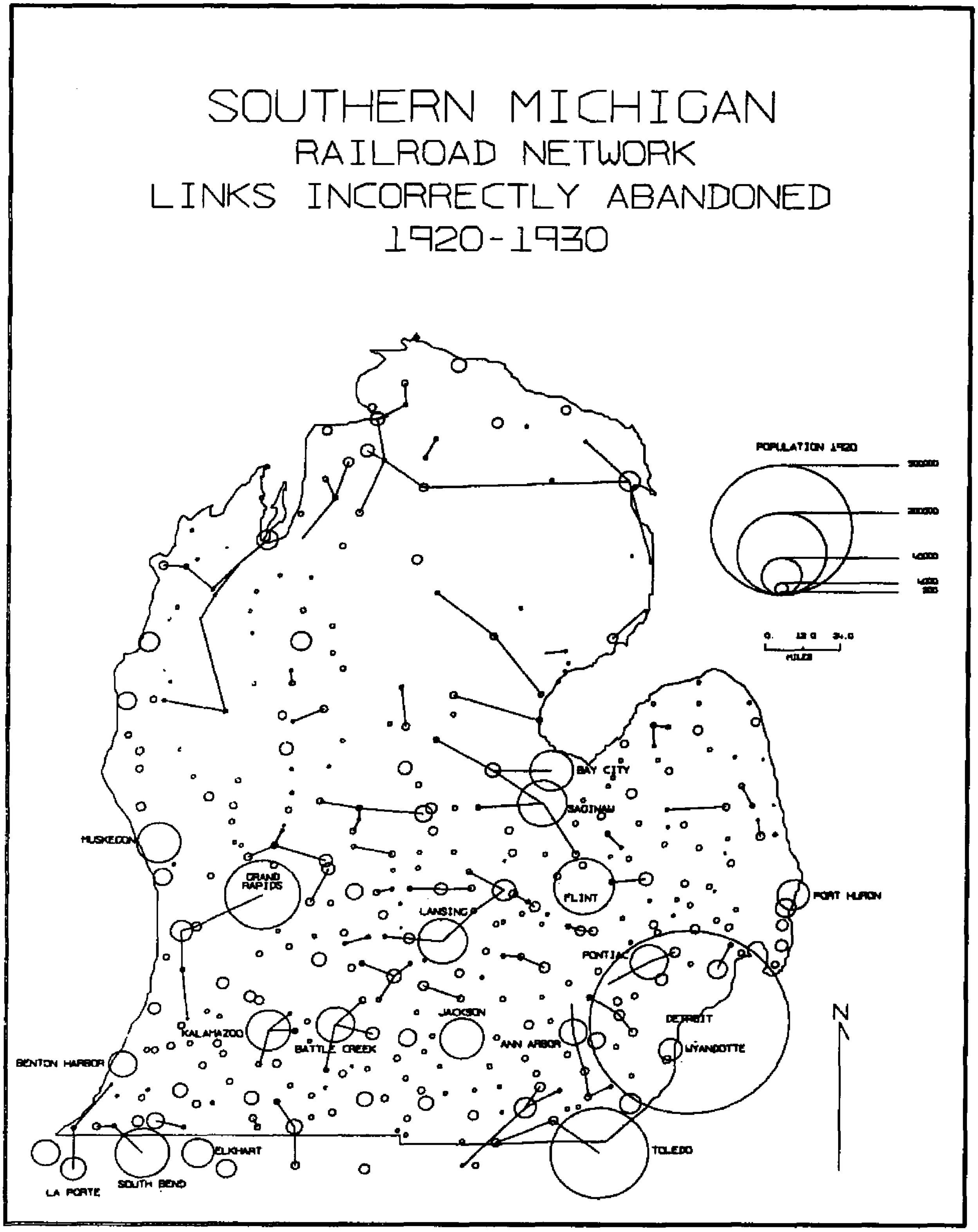
[4]It would be best in future research to sum the distances to the two nearest major cities instead of using the distance to the second closest.


SOUTHERN MICHIGAN
RAILROAD NETWORK
LINKS INCORRECTLY ABANDONED
1920-1930
POPULATION 1920
MILES
BAY CITY
SAGINAW
MUSKEGON
GRAND RAPIDS
FLINT
PORT HURON
LANSING
PONTIAC
DETROIT
WYANDOTTE
KALAMAZOO
BATTLE CREEK
JACKSON
ANN ARBOR
BENTON HARBOR
ELKHART
TOLEDO
LA PORTE
SOUTH BEND
N

MAP 36

TABLE 9.--Rank and standardized weights of the discriminant function for the decline of the railroad network of southern Michigan from 1930 to 1942[a]

	Variable Number and Name	Standardized Weight	Rank
1.	Length of the link	.209	7
2.	Population of the larger node	. . .[b]	.
3.	Population of the smaller node	.057	9
4.	Number of urban centers connected to the network within ten miles of the link	. . .	.
5.	Percentage of urban centers connected to the network within ten miles of the link	. . .	.
6.	Number of urban centers connected to the network within twenty miles of the link	.221	6
7.	Percentage of urban centers connected to the network within twenty miles of the link	. . .	.
8.	Number of urban centers connected to the network within thirty miles of the link	. . .	.
9.	Percentage of urban centers connected to the network within thirty miles of the link	. . .	.
10.	Number of connections to the smaller node	.235	5
11.	Number of connections to the larger node	.055	10
12.[c]	Distance to the nearest major urban-economic center	-.039	11
13.	Distance to the second nearest major urban-economic center	.668	1

TABLE 9.--Continued

	Variable Number and Name	Standardized Weight	Rank
14.[d]	Distance added to the nearest least cost path by the connection of the node closer to the path............	.442	2
15.	Distance added to the nearest least cost path by the link given the initial connection of the node closer to the path.................	.243	4
16.	Distance added to the nearest least cost path by the link given the initial connection of the node farther from the path..............	.346	3
17.	Population of the node closer to the path...........................	. . .	.
18.	Population of the node farther from the path...........................	-.155	8

[a]The mean score for the groups of links retained in the network was 5.096, for the group of links abandoned 6.979.

[b]The variables with standardized weights less than .1 or with high correlations with several other variables were dropped from the analysis, and the function was recalculated.

[c]The major urban-economic centers were defined as the ten largest cities.

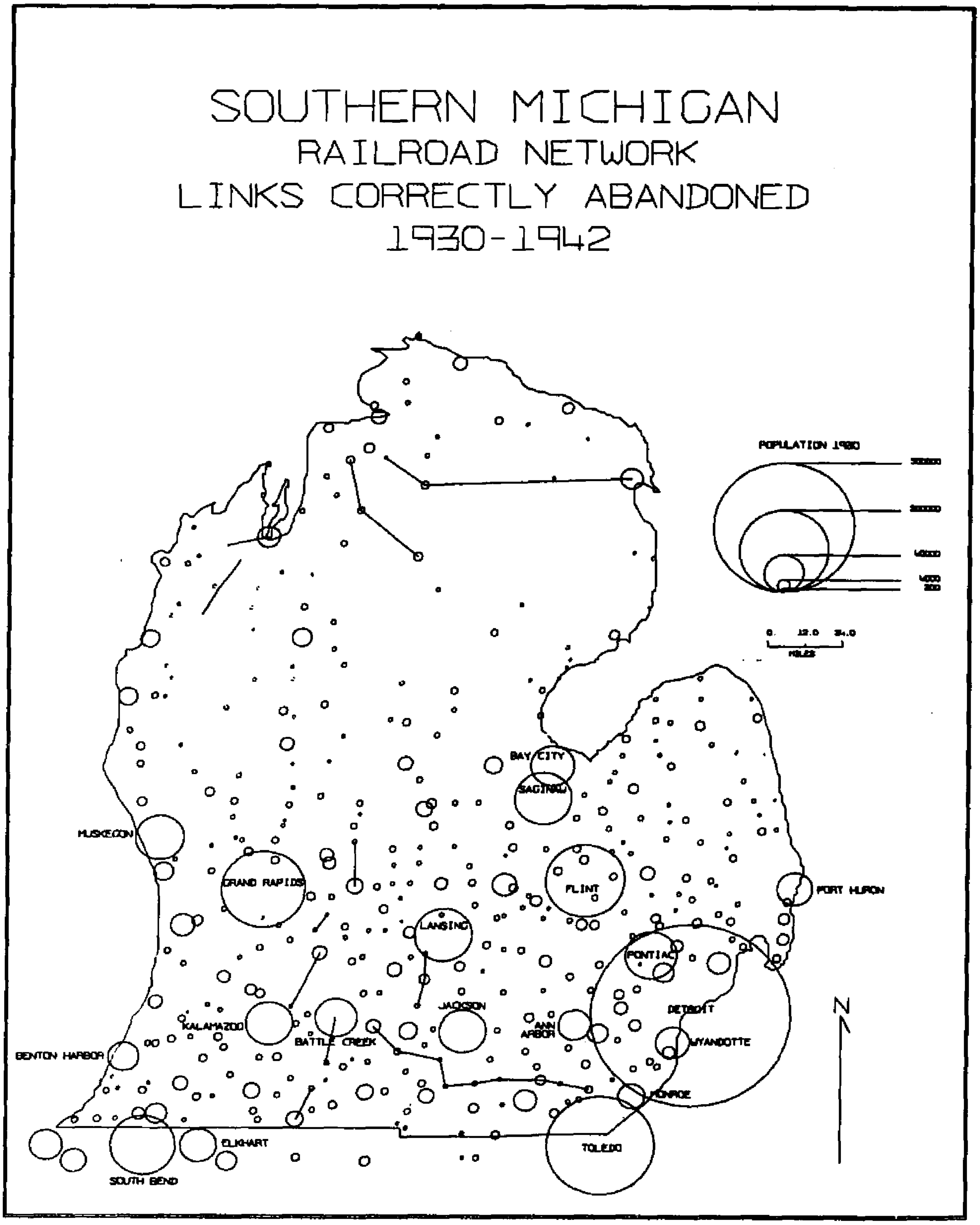
[d]The least cost paths were defined as the routes between the ten largest cities.

The potential for generating local traffic was of secondary importance in making abandonment decisions. The links with larger numbers of competitive nodes (variable 6, rank 6) were more likely to be abandoned. Plus the longer links were the least likely to be retained in the network.

The model for this period predicts 73 percent of all the decisions correctly; 83 percent of the links actually abandoned were properly defined (see Map 37), while 73 percent of the links retained in the network were identified.

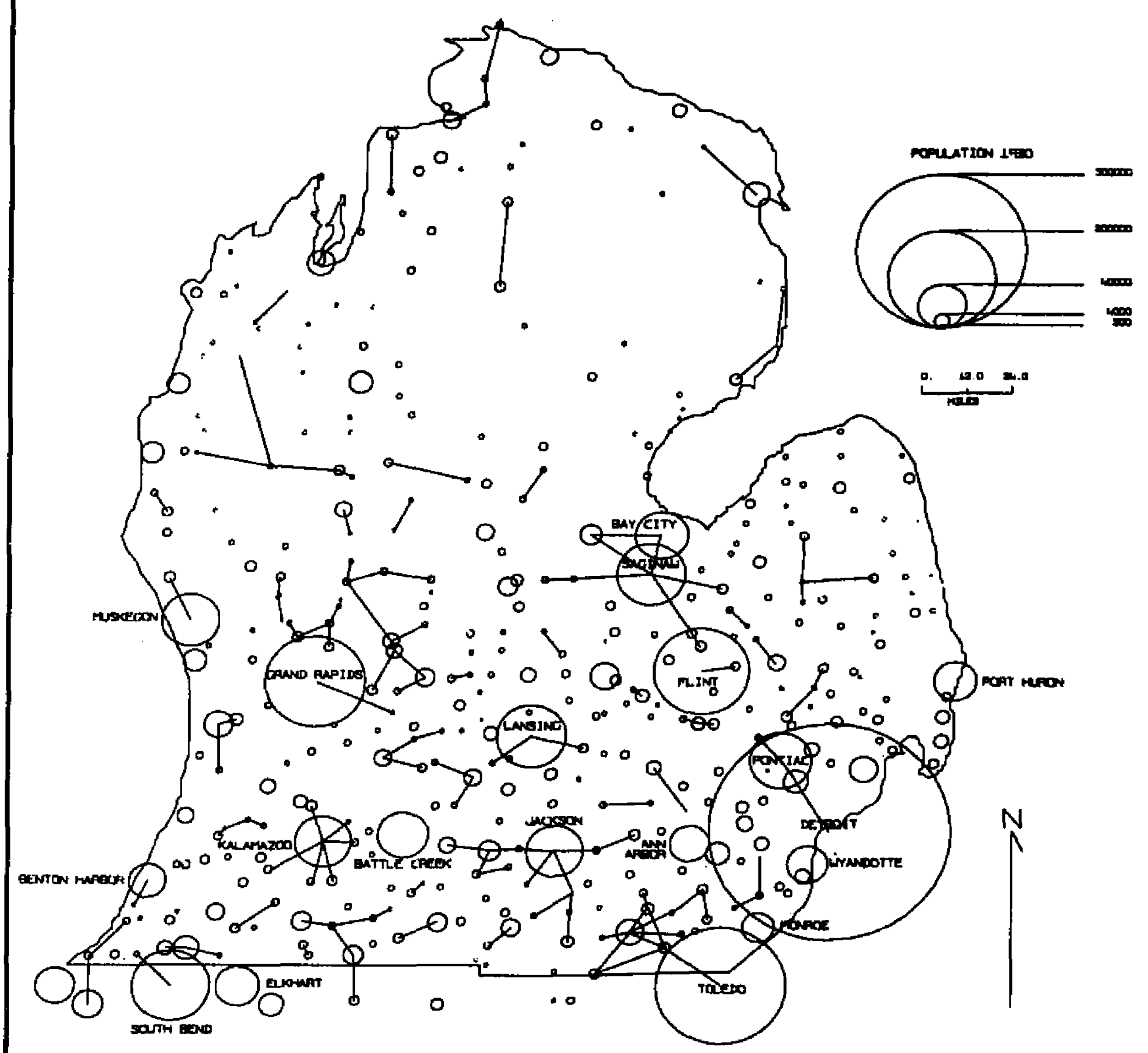
Links incorrectly retained.--During this period (1930-1942) there are seven links actually abandoned, but retained in the network by the model. Two of the links formed part of a series of abandoned links (one south of Lansing and one south of Battle Creek). It is only logical that they should be abandoned along with the other links, which were predicted correctly by the model. The five remaining links connected relatively small nodes which did not have a very high potential for carrying externally traffic generated, an important influence on the location decision

Links incorrectly abandoned.--Eleven of the links incorrectly abandoned were actually abandoned after 1942. The over prediction of the links abandoned in the vicinity of the major urban-economic centers was even greater than in the previous period (see Map 38). These errors were again related to the importance of the distance to the second nearest major city. This variable accounted for most of the misclassifications.


SOUTHERN MICHIGAN
RAILROAD NETWORK
LINKS CORRECTLY ABANDONED
1930-1942
POPULATION 1930
MILES
BAY CITY
SAGINAW
MUSKEGON
GRAND RAPIDS
FLINT
PORT HURON
LANSING
PONTIAC
JACKSON
DETROIT
KALAMAZOO
BATTLE CREEK
ANN ARBOR
WYANDOTTE
BENTON HARBOR
MONROE
ELKHART
TOLEDO
SOUTH BEND
N

MAP 37

SOUTHERN MICHIGAN
RAILROAD NETWORK
LINKS INCORRECTLY ABANDONED
1930-1942



1942-1952

The discriminant function for this ten year period is not statistically significant. Moreover the prediction of the links actually abandoned is low, only 54 percent. Therefore, it is felt that this model did not merit further discussion. One potential explanation for this lack of consistency in the decision making process could possibly be the implementation of a stricter set of rules governing railroad abandonments by the Interstate Commerce Commission during World War II.

1952-1967

During this period the most important attribute by far is the distance added to the nearest least cost path by the link (variable 16, rank 1; variable 15, rank 7) (see Table 10). The greater these distances, the more likely the link was abandoned. The path effect, therefore, had the greatest impact on the entrepreneural decisions. The remaining factors had minor influences on the decisions.[5]

Links connected to a center or sub-center of a nodal system would tend to be preferred over links connecting a less important center having fewer connections (variable 11, rank 3). At the same time, the smaller centers with a larger number of connections did not generate enough traffic to

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[5]Because of the high standardized coefficient of variable 16, all of the other attributes are interpreted as being of only minor importance in the decision making process.

TABLE 10.--Rank and standardized weights of the discriminant function for the decline of the railroad network of southern Michigan from 1952 to 1967[a]

	Variable Number and Name	Standardized Weight	Rank
1.	Length of the link..................	.333	2
2.	Population of the larger node.......	. . .[b]	.
3.	Population of the smaller node......	-.128	9
4.	Number of urban centers connected to the network within ten miles of the link...........................	. . .	.
5.	Percentage of urban centers connected to the network within ten miles of the link..................	. . .	.
6.	Number of urban centers connected to the network within twenty miles of the link........................	.264	5
7.	Percentage of urban centers connected to the network within twenty miles of the link..................	. . .	.
8.	Number of urban centers connected to the network within thirty miles of the link........................	. . .	.
9.	Percentage of urban centers connected to the network within thirty miles of the link..................	. . .	.
10.	Number of connections to the smaller node...............................	.274	4
11.	Number of connections to the larger node...............................	-.323	3
12.[c]	Distance to the nearest major urban-economic center..............	-.170	6
13.	Distance to the second nearest major urban-economic center.........	-.129	8

TABLE 10.--Continued

Variable Number and Name		Standardized Weight	Rank
14.[d]	Distance added to the nearest least cost path by the connection of the node closer to the path............	.059	10
15.	Distance added to the nearest least cost path by the link given the initial connection of the node closer to the path..................	.152	7
16.	Distance added to the nearest least cost path by the link given the initial connection of the node farther from the path..............	.740	1
17.	Population of the node closer to the path...........................	. . .	.
18.	Population of the node farther from the path......................	. . .	.

[a]The mean scores for the group of links retained in the network was 1.362, for the group of links abandoned 3.971.

[b]The variables with standardized weights less than .1 or with high correlations with several other variables were dropped from the analysis, and the function was recalculated.

[c]The major urban-economic centers were defined as the forty largest cities.

[d]The least cost paths were defined as the routes between the forty largest cities.

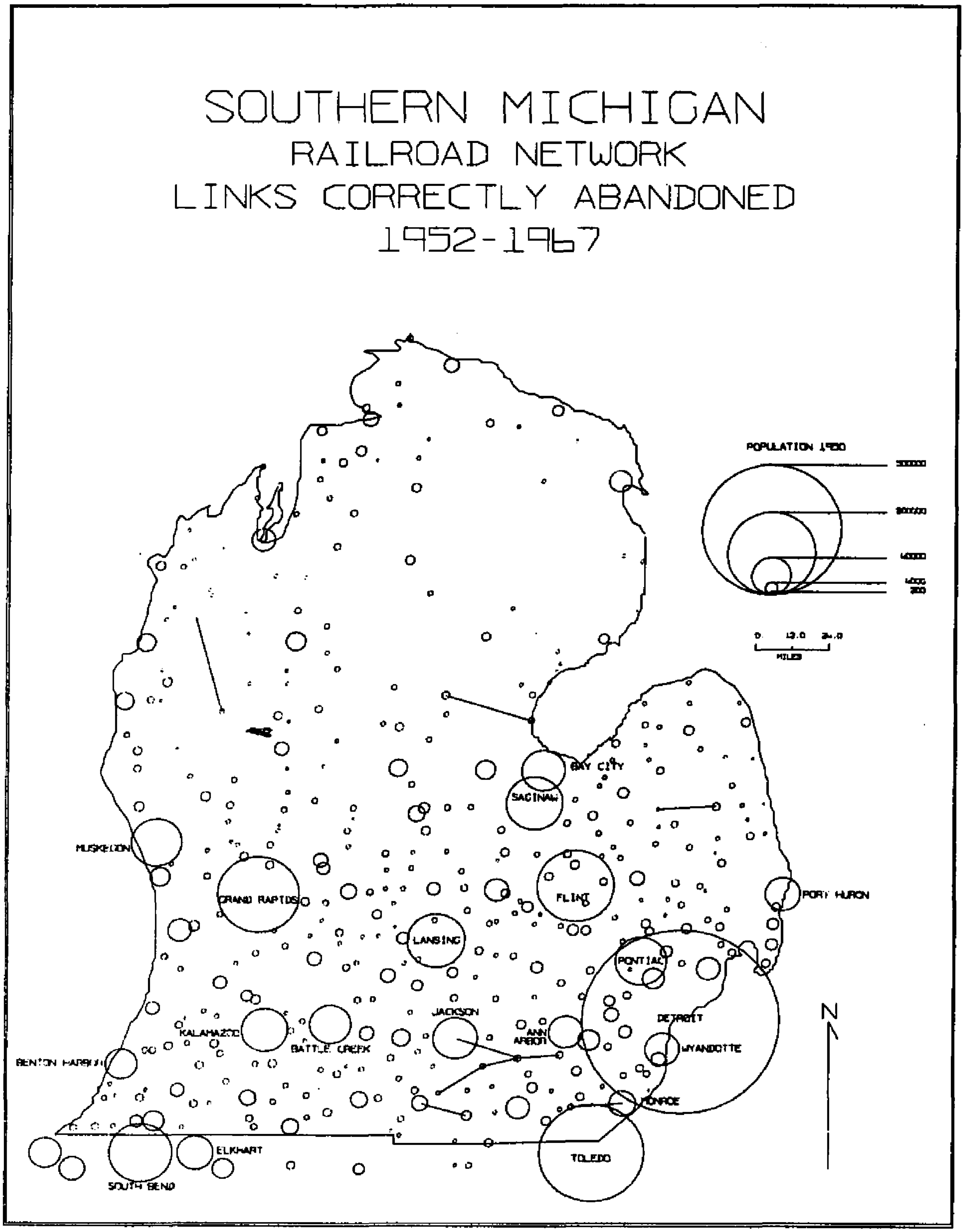
merit all of the connections (variable 10, rank 4).

The longer links (variable 1, rank 2), those links located in areas with larger numbers of competitive nodes (variable 6, rank 5), and those links joining smaller nodes (variable 3, rank 9) were the most likely to be abandoned. The links closer to the major cities were abandoned first, (variable 12, rank 6; variable 13, rank 8), therefore the distance to the urban centers was not a factor in the decision making process.

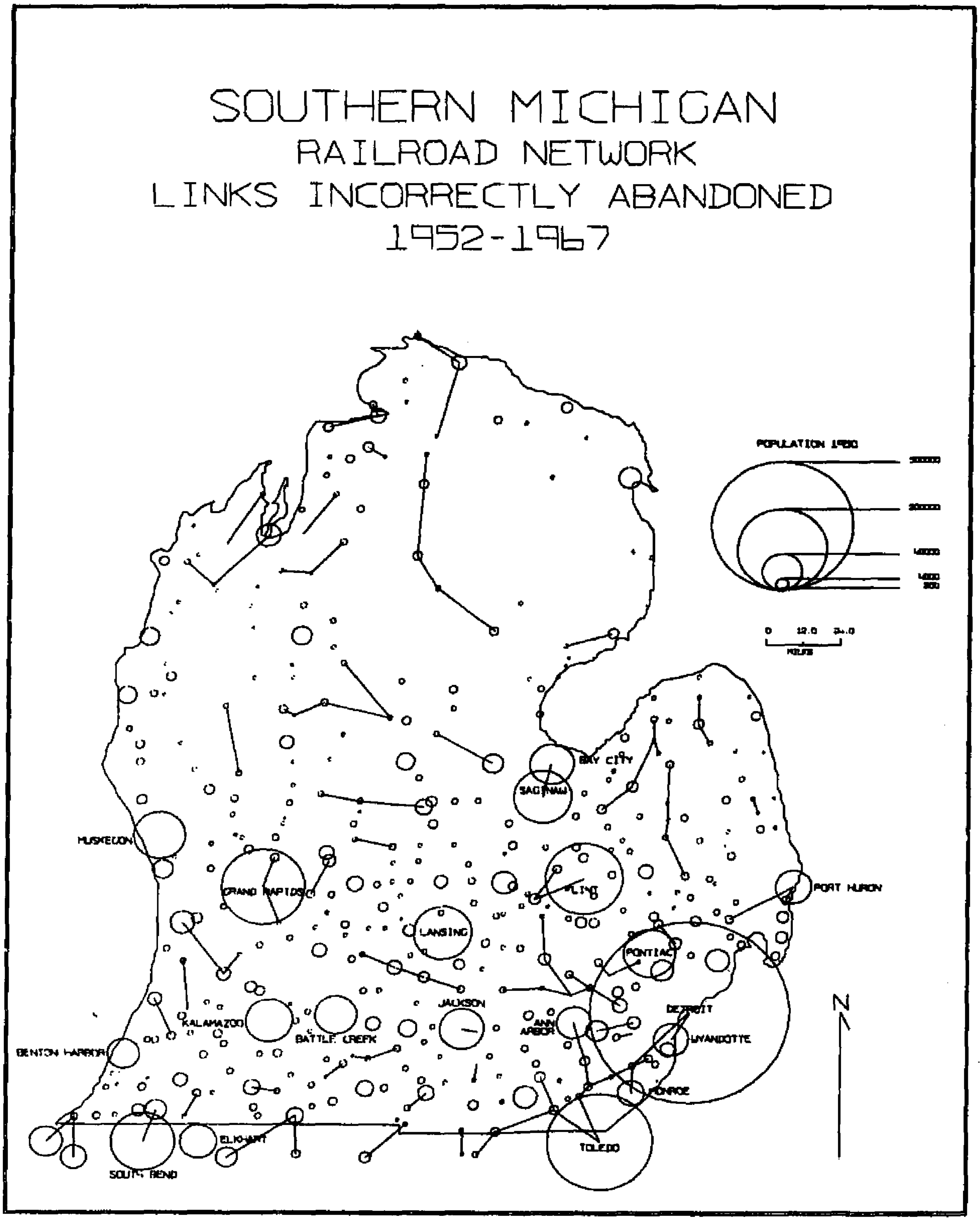
The model predicts 75 percent of all of the decisions. Of the links abandoned, 77 percent were identified correctly (see Map 39), while 75 percent of the links retained in the network were properly defined.

Links incorrectly retained.--Three links actually abandoned were not properly predicted by the model. One was part of a small railroad that went out of business. The second error was a short dead-end link which was connected to Benton Harbor. The third link misclassified joined two nodes that both had other connection by the same railroad company; therefore the railroad's potential for carrying traffic would not be affected by abandoning the link.

Links incorrectly abandoned.--Because most of the links abandoned were in the southeastern portion of the state proximal to several large cities, there is a tendency for other sets of links similarly situated to be abandoned incorrectly by the model (see Map 40). Examples can be seen


SOUTHERN MICHIGAN
RAILROAD NETWORK
LINKS CORRECTLY ABANDONED
1952-1967
POPULATION 1950
0 12.0 24.0
MILES
N
BAY CITY
SAGINAW
MUSKEGON
GRAND RAPIDS
FLINT
PORT HURON
LANSING
PONTIAC
KALAMAZOO
BATTLE CREEK
JACKSON
ANN ARBOR
DETROIT
WYANDOTTE
BENTON HARBOR
MONROE
TOLEDO
ELKHART
SOUTH BEND

MAP 39


SOUTHERN MICHIGAN
RAILROAD NETWORK
LINKS INCORRECTLY ABANDONED
1952-1967
POPULATION 1950
MILES
N
BAY CITY
SAGINAW
MUSKEGON
GRAND RAPIDS
FLINT
PORT HURON
LANSING
PONTIAC
KALAMAZOO
BATTLE CREEK
JACKSON
ANN ARBOR
DETROIT
WYANDOTTE
BENTON HARBOR
MONROE
ELKHART
TOLEDO
SOUTH BEND

MAP 40

south of Lansing, between Flint and Ann Arbor, and east of Saginaw and Flint. There is also a problem of the links along the southern border being abandoned incorrectly.

Changing Location Preferences: 1910-1967

The consistently most important factor in the decision making process was proximity to major intercity routes (path effect). In general the greater the distance added to the nearest least cost path by the link, and to a lesser extent the greater the distance from the least cost path to the link, the more likely the link would be abandoned. There was normally no trade-off of nodal size and distance. Population was not of importance in the decision making process.

There was the least consistency in the impact of the propinquity to major urban-economic centers (field effect) on the location decisions. It was the most prominent factor in the 1910-1920 period; it then declined to a position of secondary importance between 1920 and 1942; and finally after 1952 it was of negligible influence.

The potential for locally generated traffic (local interaction) was normally of secondary significance in the decision making process and was the least important of the three factors. The length of the links and the size of the smaller node were the only variables of consistent, but secondary importance. The lack of prominence of all of the population variables except the size of the smaller node would indicate that there was a threshold size of the nodes, and increases in the size of the nodes above the threshold were of little consequence in the decision making process.

The analysis of the decline of the railroad network showed that the three factors introduced in Chapter III did influence the entrepreneural decisions in the manner hypothesized. The conceptualization of network development, therefore, explains network decline better than network growth.

CHAPTER VII

SUMMARY AND CONCLUSIONS

Summary

The goal of this research was to derive a set of rules to describe the behavior of the decision makers locating the transportation network. Once these behavioral postulates were identified, it was then possible given the alternative link locations to predict the links which were constructed (or abandoned). A review of the literature indicated that this type of approach to the problem of network location was not used in previous research.

A new conceptual approach was developed in an attempt to clarify the problem of network location. It was based on the entrepreneur's perception of the anticipated amount of traffic which would be carried by potential link locations. Three concepts were hypothesized as the factors considered by entrepreneurs in making location decisions. The first concept was the potential amount of traffic generated by the nodes connected by the alternative; this factor was referred to as local interaction. The second concept, the path effect, was meant to indicate the potential of an alternative for carrying traffic between major urban-economic centers. The third factor, the field effect, was based on the premise that the amount of interaction generated externally from a potential link was a function of the distance to the nearest major urban-economic centers. Twenty attributes of the alternatives were identified as surrogates for these three factors.

To define the rules of behavior, two group discriminant analysis was used. The two groups were the alternatives accepted and rejected by the decision makers. The hypothesized conceptualization was tested using the railroad of southern Michigan between 1860 and 1967. Two sets of models were constructed, one for the growth of the network, and the other for the decline of the network, Local interaction was the most important of the three factors in the growth process, although after the first two decades the three factors were of approximately equal importance. With the decline of the network the path effect was the most prominent of the three factors.[1]

Conclusions

The success of the models in predicting link locations was moderate, generally between 70 and 80 percent of the location decisions. Many of the errors are the consequence of an overly simplified conceptualization of the network development process, and the resultant omission of attributes of the alternatives having an impact on location decisions.

[1]For a more detailed summary of the results, see the concluding sections in Chapters V and VI.

However, in assessing the value of the results of this research it is important to realize predictability alone is not the only significant consideration; increased comprehension of the problem of network location is even more important. None of the previous work has either identified location of competition as an important influence on network location, or attempted to identify the factors influencing entrepreneural location decisions; both are major contributions of this research. However as mentioned above, there still were omissions in the approach used in this work. A discussion of a few of the more important deficiencies follows.

In defining the path effect the location of competition was disregarded. There was no problem when only one path was built between two major cities. However, once the primary paths were constructed, the secondary path effect took place when routes paralleling, but away from, the primary routes were built. For example, there was a primary line running from Saginaw to Detroit to Monroe to Toledo, a secondary route was then built from Saginaw to Flint to Monroe taking into consideration the location of the competitive primary line. The simple trade-off between increased nodal size and distance added to the least cost path becomes much more complicated for the secondary routes, since a third variable, location of competition, is added, producing a three-way trade-off.[2] The over simplification of the complex real world situation should explain in part the lack of significance of the hypothesized trade-off of size and distance.

Any future models would definitely have to take into consideration the location of competitive links to avoid prediction of links providing duplication of existing facilities. This problem could be solved by simply including the reciprocal of the distance separating the two nodes in the existing network as an attribute. This variable would have a value of zero if the nodes had no connection, and a upper value of one, assuming the minimum distance separating any two nodes is one mile.

To avoid producing duplications in the network during any given period feedback should be introduced into the models. The modeling of the network would be an iterative process. The steps of the process would be as follows:

1) calculate the discriminant analysis model;

2) the link having the characteristics indicating it would be the most likely accepted would be included as part of the network;

3) all the attributes of the links would be recalculated;

4) the discriminant analysis model would be recalculated;

---

[2]The decision makers should try to 1) maximize the size of the towns served, 2) maximize the distance to competition and 3) minimize the length of the route.

5) steps 2, 3, and 4 would be repeated until the discriminant function was not statistically significant.

Unfortunately such a procedure would be very inefficient. It could be approximated by reducing the iterations to ten and locating ten percent of the links during each pass instead of a single link.

Two of the surrogates for the field effect, the number of connections to the two nodes connected by the alternative, were incorrectly conceived. These two variables indicated the avoidance of competition, and could be improved by identifying the number of connections to competitive railroad companies. The nodes with larger numbers of competitive connections should be the least likely to be accepted as alternatives. Similarly if the number of connections by the railroad company considering the alternative were also identified, then the likelihood of an alternative being accepted should increase with the number of connections.

The classification procedure used in the analysis tended to numerically over predict the smaller group of alternatives;[3] unfortunately there are not any procedures which could be substituted satisfactorily for this method. The only hope is to delimit a set of link attributes which would reduce the overlap in the groups and thus lessen the problem of over prediction.

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[3]See Appendix IV.

An issue associated with the inadequacy of the classification procedure is the method of identifying alternatives. To avoid omitting any alternatives perceived by the decision makers, all locations which could possibly be conceived as an opportunity were included. It was assumed that any alternative incorporated and not perceived by the entrepreneurs would be rejected. Such an approach produces a very large group of alternatives which were rejected, and therefore adds to the problem of improper classification.

The introduction of the direction of the growth would also improve the models. The potential for locally generated interaction would then be primarily dependent on the size of, and competition around, the terminating node. The population of the source node would be of secondary importance. Using this perspective it is more likely that the nodal population would influence location decisions. In dealing with the path effect it would not be necessary to define growth in two directions; and thus the possibility of a trade-off of nodal size and added distance is greater and more meaningful. However, introducing direction would complicate the problem of identifying alternatives; although this issue could be partially alleviated by including each alternative twice, once for each direction.

This research has added to the body of knowledge on network location, and has, therefore, contributed to the further understanding of the network development process. But, there is still a large amount of work to be done; this work has indicated a possible direction for future investigation, which should lead to a much more complete comprehension of transportation network location decisions.

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APPENDIX I

SOME BASIC DEFINITIONS

The transportation network, as conceived in this research, is a set of points and a set of line segments. The points or nodes of the network are urban centers. These nodes are joined by line segments called links, along which the interaction between the nodes takes place. In some cases two or more links may intersect to form a junction away from any node. Any such instance will be considered a cost minimizing transformation of the network, that is a "delta-wye" transformation,[1] since it is assumed a link is constructed to promote interaction between the points connected.

Transportation network development is a historical or evolutionary process, which will be defined as the changes which occur in the location of the links of the transportation network as it evolves through time. It is the process by which links are added to and deleted from the network; this developmental process is therefore one of both growth and decline.

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[1]For a discussion of cost minimizing transformations, see Martin Beckmann, "Principles of Optimum Location for Transportation Networks," Quantitative Geography: Economic and Cultural Topics, Part I, ed. by William L. Garrison and Duane F. Marble, Northwestern Studies in Geography No. 13 (Evanston, Illinois: Northwestern University Press, 1967), pp. 95-119.

APPENDIX II

IDENTIFICATION OF POTENTIAL LINKS: THE SET OF ALTERNATIVES

The nodes of the network are defined as urban places, and the links are the line segments joining the nodes. In defining the potential links the number of nodes used, therefore, influences the size of the set of alternatives.

Node Identification

The first problem encountered in identifying the nodes is that some unincorporated centers were considered by entrepreneurs to be of sufficient size to be connected to the network, but in this research it is impossible to identify these nodes because they are not covered by the population census. A second and more fundamental problem is the determination of the set of nodes which the entrepreneurs perceived to be of sufficient size to merit connection to the network. In previous studies the threshold population was arbitrarily defined[1] or was assumed to be the population of the urban places which were connected by the

[1] Garrison, "Structure of Transportation Networks"; Garrison, "Forecasting Transportation Development," pp. 97-105; Boyce, "Synthetic Transportation Networks."

network 50 percent of the time.[2] In both cases an arbitrary decision was made as to the minimum size for an urban place before its connection to the network was perceived as being economically feasible. It would appear more reasonable to identify the size of the smallest urban place that lies on the network as the population threshold for nodes. It is more realistic to include nodes that are not perceived as being large enough, in which case they will be rejected each time by the decision makers, than to omit nodes which are susceptible to being connected. Therefore, all urban centers are used as nodes in this research.

Link Set

Much of the emphasis in the previous research has been on the identification of the connections between nearest neighbors,[3] or at the opposite extreme all possible connections between nodes within some arbitrarily defined distance.[4] The latter is unacceptable from the point of view of entrepreneural perception. The procedures for identifying the nearest neighbors in the previous studies are methodologically unsatisfactory.[5]

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[2] Black, "Growth of the Railway Network"; Black, "Generation of Transportation Networks."

[3] Garrison, "Structure of Transportation Networks"; Boyce, "Synthetic Transportation Networks"; Black, "Growth of the Railway Network."

[4] Black, "Generation of Transportation Networks."

[5] See footnote 20, Chapter I.

It is hypothesized that an entrepreneur will delineate the set of links which form connections to the first order nearest neighbors of a given node as his alternatives. The method for defining first order nearest neighbors was developed by Tobler for identifying interpolation points in constructing isoline maps. The first order nearest neighbors are identified by constructing Thiessen's Polygons around the nodes. The nodes corresponding to the sides of a polygon for any given node will be its first order neighbors.

By identifying the first order neighbors of all nodes, the set of all possible alternative links will be delimited. Then by removing the links of the existing network and the links constructed from this set, the group of links rejected as alternatives can be derived.

This method is felt to be the best way of identifying the set of alternatives perceived by the entrepreneurs. Although this definition is arbitrary, it seems more justifiable than to consider connections to all other nodes or some arbitrarily defined number of nearest neighbors in various directions.

APPENDIX III

DISCRIMINANT ANALYSIS AND NON-METRIC SCALING: A CRITICAL COMPARISON

Non-metric scaling could have been used as the method of analysis instead of discriminant analysis, since it would provide important information on how the entrepreneurs ordered their alternatives. It is the only method used in the previous behavioralistic research to find rules of behavior. Therefore, it would be within the context of the problem to critically compare scaling with discriminant analysis.

Non-metric scaling was used by Rushton to construct a model of consumer behavior that identified the manner in which individuals ordered the potential destination for shopping trips.[1] But a different type of problem is involved in this research, since the entrepreneurs may not always accept the best alternative available to him, if it does not provide some minimal expected utility, or he may choose several alternatives, if they all supply a minimal level of return.

[1]Gerard Rushton, "The Scaling of Locational Preferences," Department of Geography and the Computer Institute for Social Science Research, Michigan State University.

A second deficiency of the scaling method is that it is necessary to identify attribute types, since the scaling is performed on a proximity matrix which is constructed from pairwise comparisons of attribute types. Thus the method assumes that the important variables have all been determined, and that they are few in number; for as the number of variables increases arithmetically, the number of attribute types increases geometrically and sampling error consequently increases.

In using two group discriminant analysis it is possible to identify a type of metric scaling. Employing the discriminant scores the alternatives can be located on the new scale defined by the discriminant vector. This means of the groups define the direction of the scale. Discriminant analysis has the additional advantage that the probability of group membership can be directly derived from the scale. But this method does lack a directly calculated measure of goodness of fit such as "stress" which is determined in non-metric scaling. However, it is possible to determine if there is any statistically significant difference between the actual and predicted group membership.

It is also possible to make inferences about hypothetical alternatives using discriminant analysis, assuming the discriminant scores of the two groups are normally distributed. Because the discriminant function is a linear combination of the variables, the discriminant scores for an alternative with any possible combination of characteristics can be located relative to the other alternatives and its probability of group membership can be calculated.

APPENDIX IV

MULTIPLE-DISCRIMINANT ANALYSIS AND CLASSIFICATION PROCEDURES[1]

Multiple-discriminant Analysis--Mathematical Derivation

Multiple-discriminant functions are computed as the vectors associated with the latent roots of the determinantal equation

$$|W^{-1}A-\lambda I| = 0$$

where I is an identity matrix, W is the pooled within-groups deviation scores cross-product matrix, and A is the among-groups cross-products of deviations of groups from grand means weighted by size. The A and W are both $\underline{m}$ x $\underline{m}$ matrices where $\underline{m}$ = the number of variables; the elements of the two matrices are defined as follows:

$$w_{ij} = \sum_{k=1}^{g} \sum_{n=1}^{N_g} (X_{ikn} - \bar{X}_{ik}) \quad (X_{jkn} - \bar{X}_{jk})$$

$$a_{ij} = \sum_{k=1}^{g} N_g \; (\bar{X}_{ik} - \bar{X}_i) \quad (\bar{X}_{jk} - \bar{X}_j)$$

where $\underline{g}$ = number of groups, N_g = number of observations in

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[1]This derivation is taken from William W. Cooley and Paul R. Lohnes, _Multivariate Procedures for the Behavioral Sciences_ (New York: John Wiley and Sons, Inc., 1962), pp. 117-18, 134-39.

group $\underline{g}$, and $\underline{i}$ and $\underline{j}$ run from 1 to $\underline{m}$. The matrix equation

$$(W^{-1}A-\lambda I)v = 0$$

is derived from the partial derivative of the ratio

$$\lambda_i = \frac{v_i'Av_i}{v_i'\,Wv_i}\quad, i = 1,2,3, \ldots ,r,$$

where $\underline{r}$ is the lesser of $\underline{g-1}$ and $\underline{m}$. The ratio is maximized so that the among-group sum of squares $v_i'Av_i$ will be large relative to the within group sum of squares $v_i'Wv_i$ for the discriminant functions represented by the eignvalues, λ_i, and their associated eigenvectors, v_i.

The computed eigenvectors are the coefficients of the discriminant function. To show the relative contribution of the variables to the discriminant function, these normalized vectors are multiplied by the corresponding elements of the square roots of the diagonal elements of W.

The matrix C of the centroids of the groups in the reduced discriminant space is computed by multiplying the $\underline{r}$ x $\underline{m}$ matrix of discriminant vectors, V, by the $\underline{m}$ x $\underline{g}$ matrix of group means of the original variables, M, as follows:

$$C_{(r,g)} = V'_{(r,m)} \cdot M_{(m,g)}.$$

Mathematics of the Classification Procedures

To calculate the likelihood of group membership the classification chi square is determined as follows:

$$X^2 = x_i'\ D^{-1}\ x_i$$

where D is the dispersion (variance-covariance) matrix and x_i is an $\underline{m}$-element vector of deviation scores;

$$x_i' = (X_{1i}-\bar{X}_{1.} \quad X_{2i}-\bar{X}_{2.} \quad . \; . \; . \quad X_{mi}-\bar{X}_{m.}).$$

The larger the values of the chi square, the lesser the density of the point $(X_{1i} \quad X_{2i} \quad . \; . \; . \quad X_{mi})$. The classification chi square can be calculated for each of the groups using the corresponding group means and group dispersion matrices. Two rules can be used for the assigning of group membership, they are as follows:

Rule I: An observation is a member of group j if

$$X_j^2 \leq X_k^2 \text{ , } k = 1,2, \; . \; . \; . \; ,g; \; j \neq k$$

Rule II: An observation is a member of group j if

$$X_j^2 \leq X_k^2 - \log \frac{D_j}{D_k} + 2\log \frac{P_j}{P_k} \text{ ,}$$

$$k = 1,2, \; . \; . \; . \; , g; \; j \neq k$$

where P_k is the number of observations in group $\underline{k}$. In general Rule II results in a minimum number of misclassifications since it does not assume that the size and dispersion of the groups was equal. However, there is one difficulty with Rule II. When P_j is relatively small in comparison to the relative frequency of membership in the other groups, P_k, group $\underline{j}$ will have a probability of membership which approaches zero.

Rule I was found to be more satisfactory in this research since the size of the group of alternatives accepted was generally small. If Rule II was used, all alternatives were predicted in the group of alternatives rejected. However, in using Rule I the number of alternatives accepted was significantly over predicted. It was felt that while Rule I had a larger total number of errors than Rule II, Rule I was still more meaningful than Rule II which predicted almost all of the alternatives in the larger group.

APPENDIX V

STATIC MODELS OF THE TRANSPORTATION NETWORK[1]

Garrison and Marble were the first researchers to attempt to predict network location,[2] deriving three models, two stochastic and one deterministic. The two stochastic models were actually attempts to derive an evolutionary system, but because of the arbitrary rules used to generate the networks, the models were not very successful. This lack of success is reflected in the choice of the authors to completely ignore their models in their review of the work done on transportation network forecasting.[3]

The deterministic model was used to predict the railroad network of North Ireland.[4] It is deficient (1) in the sense that it was defined within the context of North Ireland,

[1]Within the context of this research any attempt to locate a network at some period in time independent of the previous state of the system will be considered an inferred summary of all additions and deletions.

[2]Garrison, "Structure of Transportation Networks."

[3]Garrison, "Forecasting Transportation Development," pp. 97-108.

[4]The model was based on the assumption that each node is connected to its nearest neighbor, and each subnetwork is connected to the nearest sub-network along the "Belfast axis." This latter set of linkages was meant to include the "field effect" of Belfast.

(2) the threshold size of the nodes was arbitrarily defined, and (3) the links were added regardless of their length and the size of the nodes connected. Although for all practical purposes the model lacks generality, the model makes an important contribution with its implicit treatment of the link allocation process.

Boyce attempted to perfect the rules used in the nearest neighbor model of Garrison and Marble.[5] However, his work suffered from an ambiquous set of procedures; thus his work did not provide any substantial improvement over that of Garrison and Marble.

The entire process developed by Boyce was dependent on the actual number of links connected to each node; that is, the degree of the node. Link allocations were made after the _a priori_ establishment of the degree of each node. This procedure is inadequate in that the resultant network is a function of the order in which the nodes are used in the process. Starting the procedure with a different node will produce a different network.

Kansky also attempted a static description of the transportation network, starting with an emphasis on process like Garrison and Marble, only to similarly fall back to a static analysis.

Kansky made the assumption that all additions to the

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[5]Boyce, "Synthetic Transportation Networks."

network up to some point in time are controlled by and are statistically deducible from the regional characteristics at that point in time.[6] But taking this viewpoint ignores the impact of the construction of the transportation network on the regional characteristics. It is more logical to think of the relationship existing at the time of the growth, not at some future date. Decisions as to the location of a link would not logically seem to be dependent on future regional characteristics, but on those at or near the time of construction.

Kansky's model had the additional defect that it was based on graph-theoretic concepts, which are inherently aspatial; thus leading Kansky to conclude, "these indices do not say anything about locational patterns of the probable network,"[7] although it was the objective of the model to produce the actual patterns. The ultimate network generation was by an arbitrary set of rules.[8]

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[6] Kansky, Structure of Transportation Networks, pp. 122-47.

[7] Ibid., p. 136.

[8] The rule was the following: "Connect the two largest centers of economic activity; gradually add edges in such a way that the next largest center joins the largest and closest center which is already located on the network. After all selected vertices are located on the network and edges remain to be allocated, the same rule may be used again, in a slightly different form, in order to locate the additional edges; add the edges in such a way that the circuit between the first, second, and third largest center is completed, 'if meaningful'; then complete the circuit between the first, second, and fourth vertices; subsequently complete the circuit between the first, third, and fourth vertices, and so on." (Ibid., pp. 138-40.)

The research on the static description of network locations suffers from a lack of proper conceptualization of network growth as a process. There was no attempt by the researchers to duplicate the actual location decision making process over time. The researchers used an arbitrary and ambiguous set of procedures for the generation of links of the transportation network. The Garrison-Marble model provides the most substantial contribution by implicitly viewing the network location as a link allocation process.