An Analytical Technique for Identifying Freeway and Expressway Systems as Part of the Rural State Highway System

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A link-analysis technique, which relies on multivariate statistical procedures, is presented as a possible guide for designating major rural highways into freeway, expressway, and other major rural road systems. The link-analysis technique groups road links into systems on the basis of the functional characteristics of travel on each link. After the goals and objectives of the major highway systems are formulated, a criterion function is identified to select highway links to be included in each of the three systems. Measures such as average traffic volume, average trip length, and percentage of commercial vehicles are used to place road links into systems based upon a modified regionalization grouping procedure and multivariate discriminant analysis. Application of the model requires the availability of a statewide traffic model to define the existing or projected traffic demands for each road section. Also presented are the results of testing the technique on the major rural road system in southern Illinois.

•CURRENTLY, questions are being posed as to the extent and nature of the intercity highway network after 1973, the anticipated completion date of the Interstate System. At present, many states have initiated comprehensive need studies in an attempt to define the structure of the after-1973 highway network, and some states have proposed construction of a supplemental freeway system (1). For example, Wilbur Smith and Associates recently recommended construction of a 2,176-mile (at an estimated cost of $4.2 billion) supplemental freeway system for Illinois (2).

The highway planning engineer must then be concerned with determining the level of highway service to be provided in major rural traffic corridors in order to best accommodate future travel demands and also to achieve the goals established for the highway system. (Level of service can be defined in terms of operating speed, travel time, safety, volume-to-capacity ratio, and vehicle operating cost. Level of service can be implemented by degree of access control, geometric design standards, and operational measures.) Through a routine process of designating the level of highway service to be provided on each road link, the highway planner is involved in the first step of identifying statewide freeway and expressway systems.

Proper selection of a supplemental freeway or an expressway system requires that the system be identified by a uniform measure that can be applied on a statewide basis. Individual preferences and decisions should be reserved for evaluation of alternative plans that have been generated. The link-analysis technique (multivariate statistical procedure) presented in this paper identifies road links exhibiting similar travel functions by placing all road links into groups that statistically maximize within group homogeneity. The uniform identification of road links displaying similar functions

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guides the highway planning engineer in the identification of statewide freeway and expressway systems. For final designation of the systems, utilization is made of the logic that road links displaying similar travel functions should receive identical levels of service and that road links located in the groups reflecting the greatest functional importance should be provided with the highest level of service.

Rightfully, the highway engineer still retains his responsibility of evaluating the statewide highway plan on the basis of economic consequences, noneconomic consequences, and the goals established for the transportation system. Thus, the proposed link-analysis technique serves only as a guide by statistically identifying road links that accommodate similar travel functions. It is intended that the link-analysis model be sufficiently flexible to permit designation of road systems for any time period, as long as the corresponding input data (statewide traffic model) are available. From these conditions it should be possible to adopt the link-analysis technique for guiding decisions concerning the nature and extent of the intercity road building program after 1973.

OBJECTIVES

The purpose of this paper is to formulate and test link-analysis techniques that may be useful as guides for the functional classification of major rural highways into the following systems: (a) freeways (no intersections at grade, full control of access); (b) expressways (generally a divided highway, some intersections at grade, partial control of access); and (c) other major rural roads (generally undivided, most intersections at grade, partial or no control of access).

LINK-ANALYSIS TECHNIQUE

The Systems Approach

The link-analysis technique which is developed in this paper is based on a systems approach to transportation planning. This systems approach involves identifying goals and objectives of functional highway systems and establishing criteria for use in maximizing attainment of the objectives. The flow of the link-analysis technique is shown in Figure 1.

Goals and Objectives

As a first step, goals of the highway system should be formulated, as should also be the specific objectives of each of the three functional highway systems. Knowing goals and objectives, it is then possible to identify criteria that will be useful in selecting highway links to be included in each of the three systems.

Areas that have been explored in the past to formulate explicit goals for a statewide highway system include: promote safety, minimize disruption to economy and dislocation of people, promote faster travel, lower vehicle operating costs, maximize return on investment in transportation facilities, promote development, improve the environment and conserve resources, provide transportation service to all persons and areas, promote national defense.

Objectives of providing different major functional rural highway systems might include the following:

1. Provide a relatively uniform level of service for each system, with due regard to the functions of each system: (a) higher levels of service for systems planned predominantly for high-volume travel and/or for long trips (interstate and between major metropolitan areas); and (b) lower levels of service for systems expected to provide both land-access functions and to accommodate intermediate-length trips.
2. Provide for spacings and network configurations for each functional major rural highway system so as to maximize volumes of long-distance travel (and commercial travel) on those systems with the highest levels of service, with due consideration to improving the environment and minimizing disruption to the environment and minimizing disruption to the economy and dislocation of people.

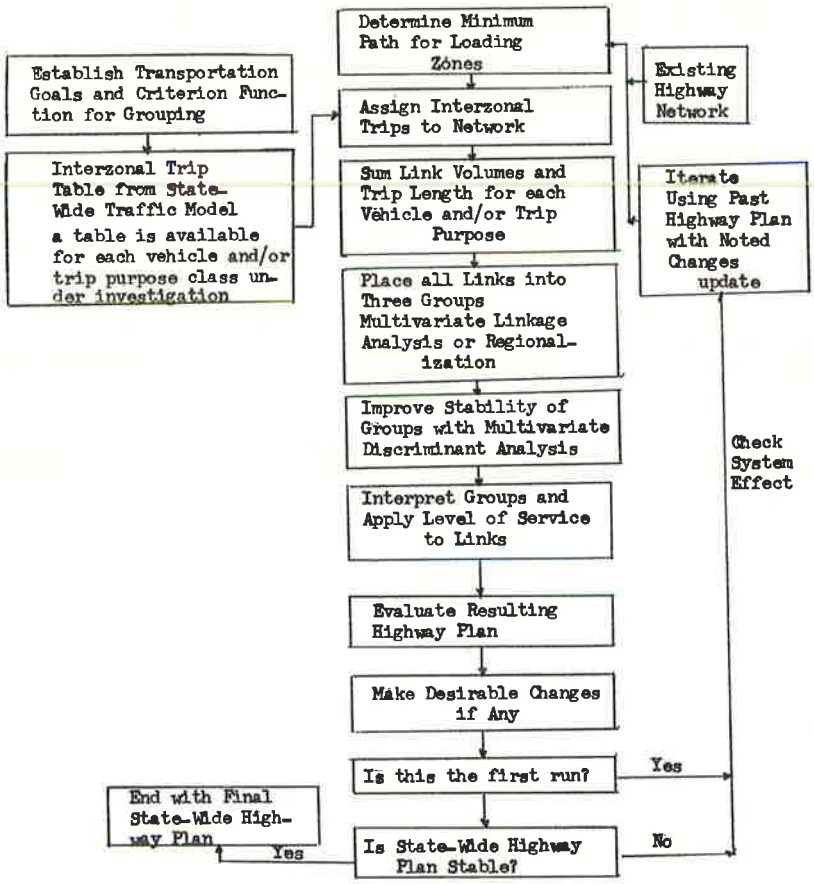


Figure 1. Link-analysis technique for identifying major rural highway systems.

3. Allocate resources to each functional system so as to maximize the return on the investment in transportation facilities.

4. Plan systems for both present and future demand, considering present development and travel desires, potential future growth and development, needs for recreation, and needs for preserving capacity and safety through access control.

Criteria for Evaluation

These objectives must be translated into quantitative measures or criteria for use in evaluating alternative functional highway classification plans, as shown in Figure 1. The criteria provide standards that can be used to measure the functional importance of various segments of the different alternative road systems.

For example, it may be assumed that certain road links displaying a high total volume in which long-haul, interstate trips, commercial vehicles, and work trips predominate will justify the highest level of service. Other measures might include the amount of recreational travel, governmental and business travel, social travel, industrial travel by segments such as mining, lumbering, or argiculture, and military travel on each road link (3, 4). The selection among the many measures available depends primarily on the capabilities of the corresponding statewide traffic model and the public policy decisions underlying the proposed function of a highway network. (The Automotive Safety Foundation identifies roads of statewide interest by their location in connecting the seats of state and county governments and other principal communities of the state and adjacent states, by the greater volume of traffic served, by their superior

service to national defense, and by their usage by long-distance commercial and passenger motor vehicle travel. The past criterion formulated by the Automotive Safety Foundation serves only as a guide. The link-analysis approach assumes that with the availability of statewide transportation goals the highway planner can specify an appropriate criterion function.)

Identifying expressway and freeway systems is then the process of grouping road links into one of three classes (freeway, expressway, state arterial) depending on the measures listed above. Any measures felt to be important could easily be included in the analysis if the pertinent data for each road link are available. The primary emphasis is placed on measures that reflect a road link's function in terms of traffic movement and not of land access.

Major Steps in Applying the Link-Analysis Technique

Methods of Grouping—Given the measures of trip length, volume, percentage of commercial vehicles, percentage of work trips, and percentage of interstate trips, the road links then must be placed into three distinct groups. It is necessary that each road link be placed into only one group and that all road links be placed into one of the groups.

Many methods of grouping items into classes exist such as elementary-linkage analysis (5), regionalization (6, 7), cluster analysis (8, 9) and integer programming (10). Regionalization and elementary-linkage analysis are selected as being most applicable to highway classification because they are both able to handle multivariate data and can be easily manipulated with the electronic digital computer. Only a modified form of regionalization will be discussed in this paper.

Modified Regionalization—Regionalization as applied to functional classification will differ slightly from its traditional approach as first published by Berry (6, 7, 12). In the ensuing analysis, the measures identified for grouping have been selected a priori. Each measure is given equal weight and if two measures are redundant or measure the same fundamental concept then that concept has been assigned a weighting double that of the other variables. Also, it is assumed that the number of groups to be identified is known prior to the grouping analysis. (This study is concerned with the development of a methodology or an approach toward grouping road links. Thus, the objective of the study is not to define how road links can be differentiated, but rather to present an approach toward placing road links into preselected groups. Through factor analysis, redundancy in measures selected in the criterion function can be identified, but without a dependent variable or correct answer. Selecting appropriate measures and weighting these measures are basically policy decisions. However, in further research it would be interesting to determine how a resulting classification plan is affected by the selection and weighting of the policy variables.)

Regionalization is a procedure used to combine n items, each associated with m measures or variables, into a smaller number of items by a stepwise-grouping process. The stepwise grouping combines n items into n-1 items, n-2 items, . . . 1 item by combining those two items that demonstrate the least multivariate distance. Two grouped items then have their multivariate distances replaced by the distance to their centroid. Distance is measured as

$$D_{jk}^2 = \sum_{r=1}^{m} (X_{rj} - X_{rk})^2$$

where

X_{rj} = variable r for link j, r = 1. . . m,

X_{rk} = variable r for link k, r = 1. . . m, and

D_{jk}^2 = squared distance between link j and k.

Distance measures the amount of similarity between links based upon m observations. Each link can be located as a point in m dimensional space. A pair of links with identical

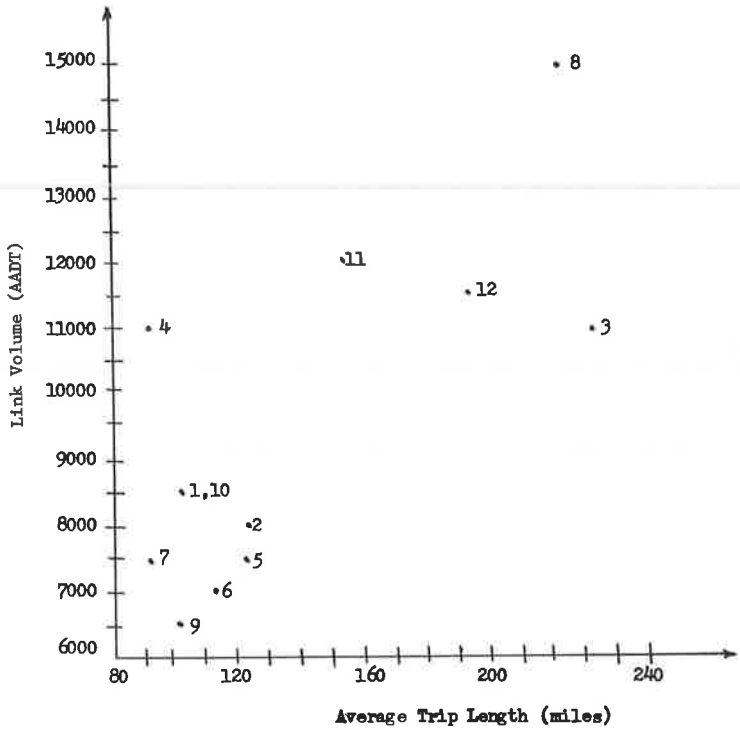


Figure 2. Road links in two-dimensional space for example road network.

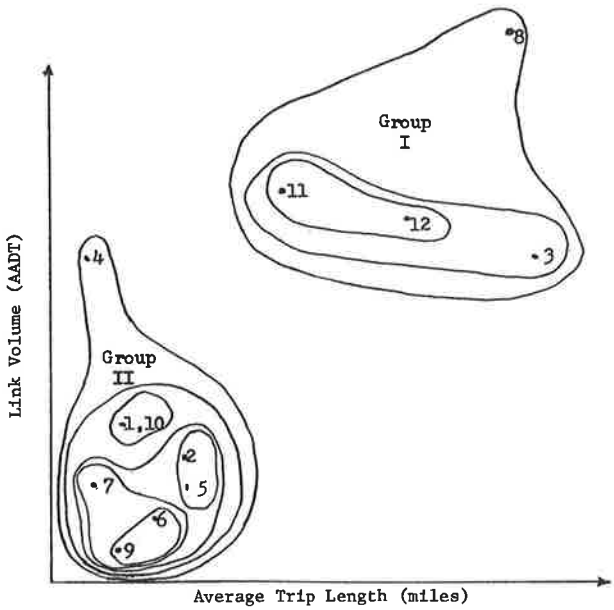
scores on all dimensions has zero distance. Points close in m dimensional space have small distances, and those links can be considered similar. Dissimilar points have high distances in m dimensional space. Grouping is conducted to minimize within group distance. Ahmad (11) presented a detailed outline of the procedure involved in a stepwise regionalization grouping process.

A simplified example will be worked for a twelve-link road network with associated measures of average trip lengths and volumes. Although grouping on the basis of two measurements provides little challenge, the approach can easily be extended up to m measures or dimensions, which is beyond visual capabilities. In two-dimensional space, these road links will be plotted as shown in Figure 2.

These observations are standardized to zero mean and unit variance in order to remove the effect of measurement units upon the grouping. Standardization permits volume measured in vehicles per day to be associated with trip length measured in miles. Otherwise, volume with a higher absolute unit would dominate the grouping procedure, and road links would become grouped solely on the basis of this one measurement.

Output from a stepwise-grouping routine yields the hierarchical ordering of these group combinations shown in Figure 3. Two distinct clusters are identified, and members in Group I (3, 8, 11, and 12) would be assigned a higher level of service by virtue of a higher loading on the link volume and average trip length variables. Road link 4 is a choice candidate for entrance into Group I and should receive further attention through a discriminant analysis.

Discriminant Analysis—Discriminant analysis can be used to differentiate among groups of road links based upon a series of associated measures available for each link. A linear combination of measures is selected that best discriminates among the groups. Discriminant analysis requires that the group membership, group means, and variance must all be specified. Thus, discriminant analysis can be used to check and improve existing groups, but not to create groups. Also, discriminant analysis can be



Step	Groups Combined	Step	Groups Combined
1	1 & 10	7	11 & 12
2	2 & 5	8	3 & 11
3	6 & 9	9	1 & 4
4	6 & 7	10	3 & 8
5	2 & 6	11	1 & 3
6	1 & 2		

Note: Groups are redefined by the lowest numbered member in the group.

Figure 3. Hierarchical grouping of road links to two distinct groups.

used to place an unclassified item from the same population into one of the existing groups. One interesting aspect of discriminant analysis is the determination of each road link's probability of group membership in each of the designated groups. Thus, road links are regrouped on the principal that each item be assigned to that group for which it demonstrates the highest probability (13). Like grouping, discriminant analysis is adaptable to computer processing. The theory and application of discriminant analysis is covered by Hoel (14) and Cooley and Lohnes (13).

Previously, either of two grouping techniques, regionalization or elementary-linkage analysis, was utilized to form initial groups. Discriminant analysis can then be used to determine if road links 1, 2, 4, 5, 6, 7, 9, and 10 are best assigned to Group I and if road links 3, 8, 11, and 12 are best assigned to Group II. As previously mentioned, the location of link 4 is of particular interest in the testing procedure. Also, an unclassified road link can be classified through discriminant functions.

An initial discriminant function was developed as both volume and average trip length were found to be significant variables for discriminating between the two groups. As shown in Figure 4, the two dimensions are collapsed into a one-dimensional index through the discriminant function. Visually, it appears that road link 4 is best associated with Group II and not Group I. The discriminant-analysis output indicated that the probabilities of group membership are high for all road links in their initial group except for road link 4. The assignment of link 4 to Group II is then recommended, and the discriminant analysis is recomputed to check on the desirability of such a change in

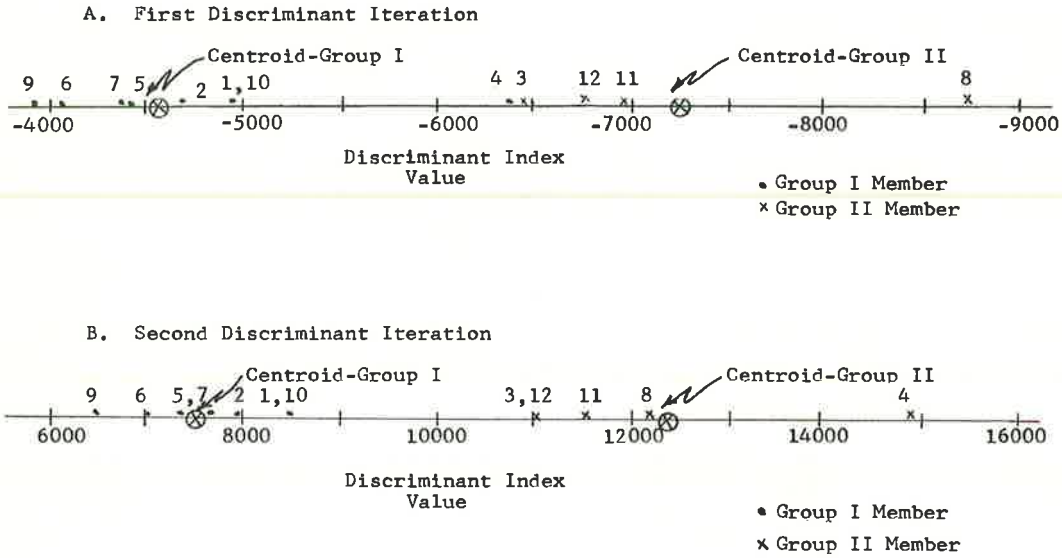


Figure 4. Collapsed two-dimensional discriminant.

group membership. Group membership probabilities indicate that link 4 is indeed best assigned to Group II.

A highway plan has then been developed based upon the assumption that Group I links form the freeway trunkline highway network and Group II links form the arterial system.

In addition to its use in improving existing groupings, discriminant analysis can be used to assign an unclassified road link to a system. For example, suppose some road link, 13, in the study area has a given volume and trip length. Should it be provided with an arterial or freeway level of service? The second discriminant function could be used to indicate to which group the new road link belongs.

Evaluation of Grouping Analysis—Problems arise with this grouping technique and, in fact, with all presently developed grouping methods because a truly optimal stage cannot be determined nor defined. Individual groupings cannot be evaluated against some desired optimum goal, and the most effective improvements cannot be identified until acceptable replication of this goal is achieved. It is never known if some better answer, measured in terms of minimizing within group variance, might exist nor how this better answer can be achieved within a feasible number of examinations. However, it is felt that for the purposes of designating road links to systems, an optimal grouping is not generally required. Any conscientious pursuit of the optimum represents an appreciable improvement over just relying upon subjective decisions in formulating a major statewide highway plan. The analytical-grouping technique can be used to create uniformity of plan formulation over both time and space. It represents an improvement over what the human mind could conceivably comprehend on a statewide basis. As improved algorithms are developed for grouping, they can easily be substituted into the model.

Extension of the link-grouping method would also allow minor reappraisals of the highway network. Based upon unexpected changes in traffic flow patterns, a link could be checked against existing group membership requirements in order to review if it might warrant reclassification. Naturally, these changes must be kept minor; otherwise flow on the entire network will change as will the definition of group membership. In the short run, such an approach might be employed as a hedge against pressure from special interest groups and as a periodic reevaluation of the plan.

Interpretation of Groups—The two distinct groups of road links formulated above must still be assigned a level of service in accordance with the principle that those links

demonstrating the greatest functional use, measured in terms of the defined criterion function, be assigned the highest level of service. To these two groups, a level of service package defined either as a freeway, expressway, or trunkline arterial road will be applied. Identification of a desirable state highway system depends on a limited sensitivity analysis. Answers should be gained to the question: What is the consequence of either limiting or eliminating investment in a state freeway or expressway system?

Evaluation—Finally, the link-analysis plan must be evaluated and tested for system effects and network consistency. The system effects are used in this discussion to represent the diversion of traffic among road facilities as the level of service provided on these roads is changed. Thus, upgrading a two-lane rural highway to freeway standards will divert some traffic off parallel routes. Sudden changes in level of service must be avoided so that a motorist is not subjected to situations of high accident potential. Approximate rules of network consistency can be developed from existing design practices, accident records, and logic. A sensitivity analysis can be applied to test the impact of these consistency rules on the final classification plan.

Output from the link-analysis plan results in a proposed plan that must still be evaluated against stated objectives, local needs, and aspirations as expressed through the transportation goals.

Before a plan can be accepted, it must be determined whether upgrading the level of service on one road link will not significantly disrupt travel patterns. Thus, these travel patterns must be recomputed utilizing the proposed new freeway and expressway plan and thus new travel times in place of the original highway network. If no substantial changes in link assignment are encountered, then the plan can be assumed acceptable. Otherwise, the link-analysis and evaluation process must once more be repeated until two successive iterations yield the same result. Alternatively, the iterative technique can be used to test the implication of various alternative road plans that have been proposed. In this sense the model becomes a testing device, but originally it served as a guide to the development of these alternative plans. In addition, transportation planners are given the opportunity to work with future travel projections and not just present travel trends.

Ultimately, it is not only desirable to reassign travel to the proposed highway network but also to identify how highway investment has altered trip generation rates and trip distributions. In rural areas, highway accessibility can have a definite influence on both the desirability of making a trip and the desirability of making a trip to a given trip end. Designation of freeway and expressway corridors will alter link travel times and will alter the time separation of urban places; this can influence the relative attractiveness of making a trip and selecting a trip end. Tracing these system effects back to the trip generation and trip distribution models is feasible within the context of the proposed methodology.

APPLICATION OF LINK-ANALYSIS TECHNIQUE TO STUDY AREA

Study Area

In order to illustrate the application of the link-analysis technique to designating major rural highway systems, the model was applied to a study area located in southern Illinois. All major rural roads in the study area, as defined by the intercity travel network (2), were identified either as a freeway, expressway, or arterial trunkline highway based upon 1985 projected travel demands (15). Because travel data were assigned only for a portion of routes in Illinois, and routes in adjacent states were not considered, differences from the Smith plan (2) can be expected.

The study area's road network includes all the Interstate and U.S. numbered highways, and most of the Illinois numbered routes. In all, 131 road links are included in the link analysis. These major highway links were identified from the traffic model as the road section between intersections with other roads. For purposes of traffic assignment, 511 road links and 347 nodes were considered.

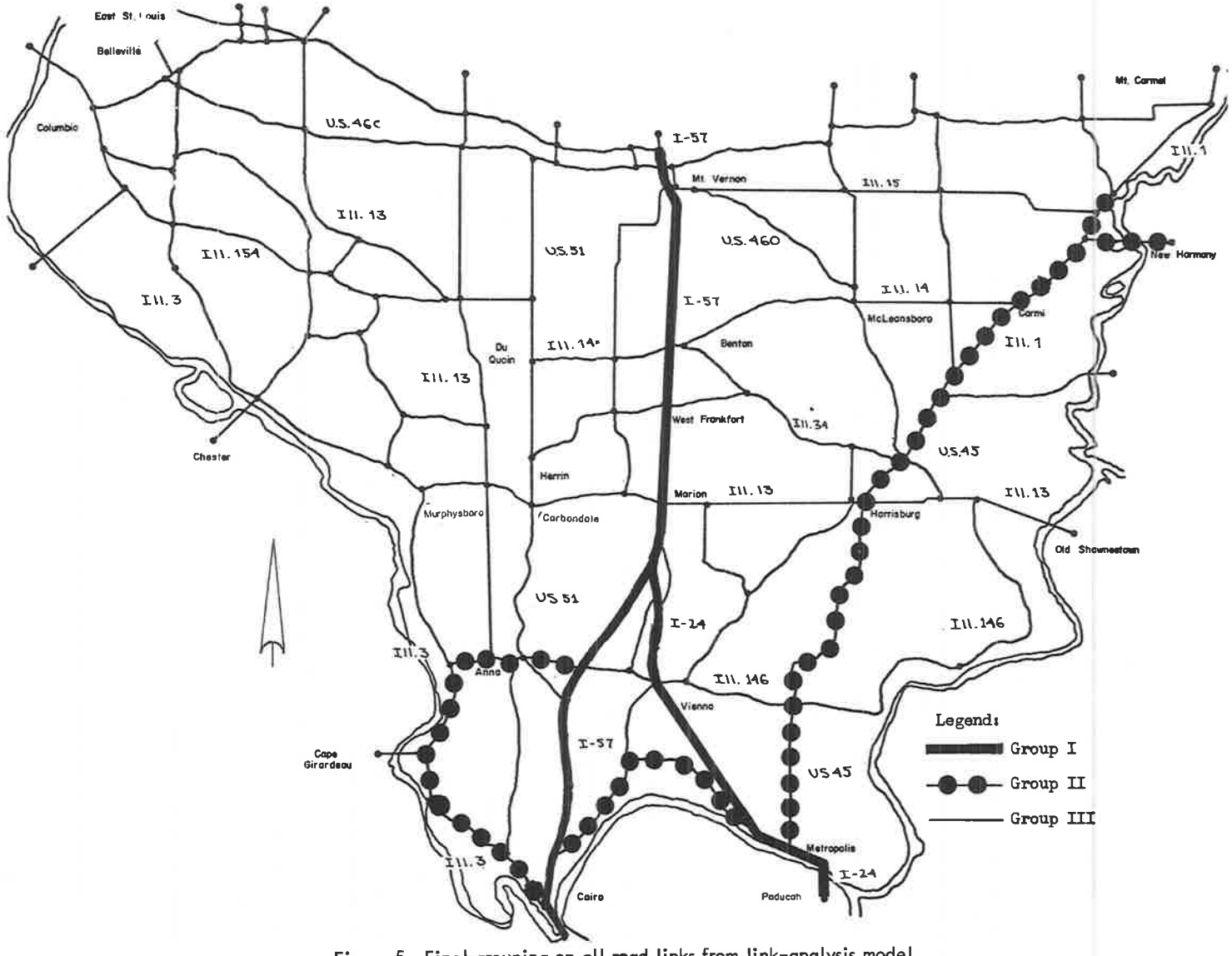


Figure 5. Final grouping on all road links from link-analysis model.

TABLE 1

MEAN VALUE OF EACH MEASURE FOR THREE GROUPS OBTAINED FROM LINKAGE ANALYSIS

Group Number	Number of Members	Volume (AADT)	Percent Trucks	Average Trip Length (miles)	Percent External Trips
I	18	25,190	29.9	238.4	85.3
II	19	4,863	29.7	90.3	75.6
III	94	2,300	29.2	57.9	18.8
Average for all groups		5,817	29.4	87.5	36.2

Method of Applying Link Analysis to Study Area

The 131 network links were grouped on the basis of four measures available as output from the traffic model. These four measures included:

1. Link Volume—The average annual daily traffic (AADT) on the maximum utilized portion of each road link was presented as a measure. The AADT was obtained directly from the traffic model.
2. Trip Length—The average trip length of vehicles using the maximum utilized portion of each road link was presented as a measure. However, the traffic model provides estimates of trip lengths for travel only within the State of Illinois. Thus, trip length cannot reflect the true importance attributed to roads serving interstate travel.
3. Percent Trips External to Illinois—The percentage of trips having at least one trip end external to Illinois was presented as a measure.
4. Vehicle Type—The percentage of trucks on the maximum utilized portion of each road link was presented as a measure.

Due to the availability of only four measures, the modified-regionalization concept of grouping was adopted for the link-analysis mode. Discriminant-analyses iterations were then conducted to determine the final grouping of road links. The availability of a traffic model having a greater number of vehicle class and trip purpose stratifications would have made it possible to substantially increase the number of measures included in the analysis.

Application of Link-Analysis Approach to Study Area

A major rural highway plan was developed for the study area based on the characteristics of each road link's volume, percentage of trips external to Illinois, and average trip length. The plan was prepared from a grouping analysis conducted using the criteria that those road links are combined that are most similar (measured as minimum distance between group centroids). Six distinct road systems were noted as output from the first grouping analysis. Included in the six groups were three groups that consist of two members or less. These minor groups were placed within the three primary groups, and their group placement was tested through six discriminant iterations that were conducted until each road link was placed in the group for which it has the highest probability of group membership. Figure 5 represents the output from the sixth discriminant analysis; three road systems are identified. Interpretation of the average volume, trip length, and other characteristics for the links in each group defines the functional hierarchy of the groups. For example, Table 1 identifies the characteristics associated with each of the three road systems identified from the link-analysis plan shown in Figure 5.

Group I displays the greatest functional importance based on the variables selected in the criterion function, and should then be provided with the highest level of service. Thus, Group I links would represent the freeway system, Group II the expressway system, and Group III the arterial system. Knowing the availability of funds and

transportation goals, the engineer could also evaluate the following alternative systems through a sensitivity analysis:

Alternative 1 (3 systems)
Group I, freeway; II, expressway; III, arterial.
Alternative 2 (2 systems, funds readily available)
Group I, freeway; II, freeway; III, arterial.
Alternative 3 (2 systems, funds restricted)
Group I, freeway; II, arterial; III, arterial.
Alternative 4 (2 systems, funds severely restricted)
Group I, expressway; II, arterial; III, arterial.

Through further analysis it was possible to subdivide the previously defined second group into two separate groups. Thus if priorities had to be assigned to a supplemental expressway or freeway system, the link analysis approach could be extended to provide stratification within a composite group. The final step would include an evaluation of the resulting plan vs other alternative plans and the transportation goals.

Limitations

Limitations of the link-analysis approach include the following points:

1. The link analysis technique was never tested for system effects and considered only four travel parameters, some of which are highly dependent.
2. The link analysis model was applied totally on a regional basis without consideration for the rest of the state. Thus, it is quite possible a Group II road link in southern Illinois would be identified as a Group III road on a statewide basis.
3. The link analysis technique was concerned exclusively with the travel function of highway classification. No attempt was made to reflect the land-access nature of these road sections or to identify how these roads might contribute to the region's economy.
4. No attention was given to urban situations except to provide connecting links to the rural system.
5. No attempt was made to reflect how trip generation and distribution might be affected by the relative highway network selected for testing. It is anticipated these two considerations would tend in the direction of justifying the network being tested.

CONCLUSIONS

The following conclusions may be drawn:

1. Intercity traffic models that estimate projected travel demands are applicable to identifying freeway and expressway systems as part of the rural highway system.
2. The link-analysis technique can be used to identify freeway and expressway systems consistently on a statewide or regional basis and can include future traffic projections as well as tests of system effects. The link-analysis model is sensitive to transportation goals and local needs and aspirations; it should prove useful in developing policy decisions regarding the status of the after-1973 highway program.

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