Inventorying an Arterial Network for Computer Assignment: Methods and Implications

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•HISTORICALLY, the inventory of transportation facilities has accompanied land-use and origin-destination surveys as one of the three major inventories of a transportation study. This inventory provides the base for determining the deficiencies of the existing arterial network and the starting point for planning future improvements. Of prime importance is the use of the inventoried network for traffic assignments, and the requirements of this assignment process dictate many of the criteria for designing the inventory.

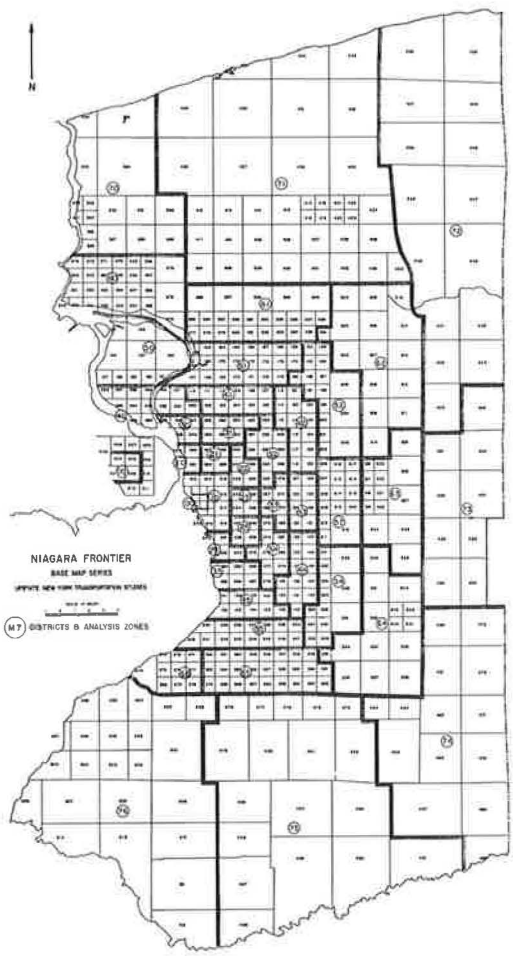

Figure 1.

The inventory must express the arterial network in a numeric or mathematical form since the traffic assignments are accomplished by use of computers. The inventory must also be designed to accommodate network revisions so that traffic assignments can be made on:

1. The present network.
2. The present network plus committed construction.
3. The present and committed system plus additional facilities planned to meet future traffic demands.

Finally, the methods developed for inventorying the facilities must also make it possible to code the network rapidly so that it can be tested early in the study process by initial traffic assignments in order to calibrate the assignment model for future assignments.

Based on previous experience it has generally taken six months or longer to inventory and code an arterial network for a study area the size of the Niagara Frontier before the first traffic assignment could be made to the network. A six months' inventory would have produced an impossible scheduling problem for the Niagara Frontier Transportation Study. It was, therefore, necessary to develop a method that would meet the requirements

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above and at the same time produce an inventoried and coded network in a minimum amount of time.

This paper describes the method developed by which the arterial network of Niagara and Erie counties was inventoried within two months. This two-county area has a population of 1,300,000 people, and the network, as finally defined, consisted of 3,900 miles of streets and highways, described by 2,020 nodes and 3,330 links. Essentially a paper survey, the inventory involved a minimum amount of field work to supplement the available data on the highway and street characteristics of the study area.

ORGANIZATION OF STUDY AREA

In addition to the arterial system within Erie and Niagara counties, a skeletal network within adjacent counties was selected and inventoried to simulate trips from these external areas.

As a first step in organizing this total area, a ¼-sq mi grid was laid out over Erie and Niagara counties with the X-Y axis oriented east-west and north-south, respectively. This grid was then used to organize the two counties into 514 traffic zones ranging in size from ¼ sq mi to 16 sq mi, with the size depending on the density of development. The basic grid used was identical to that used in coding the land-use survey. All traffic zones were made multiples of these quarter square mile areas, thus readily permitting the summary of all land-use data by traffic zone. The external area was similarly organized into 31 traffic zones, however, no basic underlying grid was used. Instead, each county was generally divided into four traffic zones of equal size by a pair of north-south and east-west lines.

To provide a basis for the orderly numbering and the grouping of traffic zones into districts, a system of rings and sectors was laid out along zone boundaries. These ring and sector boundaries along with the layout of traffic zones within the study area are shown in Figure 1. The rings are essentially concentric belts with a common origin at Niagara Square in Buffalo. Sectors are wedges of approximately 36 degrees radiating outward from the common origin of the rings. Section boundaries have been oriented generally to bracket outlying communities.

Each district is identified by the 2-digit number enclosed in a circle. These numbers correspond to its ring and sector location. Once the traffic zones were grouped into districts they were then numbered from 001 to 551, using consecutive numbers within each district.

Generally the zones within a district were numbered in a serpentine fashion. However, in districts where a cluster of smaller zones, representing a community, was encountered, the smaller zones were numbered consecutively before proceeding with the orderly numbering of the larger zones. Modifying the numbering system within a district in this way permits the grouping of data for communities in outlying areas.

DEFINING THE ARTERIAL SYSTEM

The arterial highway system of the Niagara Frontier is defined as the network of streets and highways that provides the basic travel paths for the interzonal movement of traffic throughout the study area.

This definition is particularly applicable since present computer assignment techniques require the load node or centroid of each traffic zone to be interconnected by the arterial system so that there is access from each zone to every other zone. In order to provide this continuous interzonal access, it was necessary to include many different types of facilities in the arterial network. These facilities ranged from expressways to narrow 2-lane conventional highways and also included a few "artificial" streets. The latter were introduced as a result of adopting a grid-type layout of traffic zones to facilitate data handling that in some instances produced zones with no presently developed street or highway access.

Within the definition, arterials were classified into five distinct types: (1) major street and (2) secondary street (both surface streets); (3) expressway; (4) surface-to-expressway ramp; and (5) expressway-to-expressway ramp.

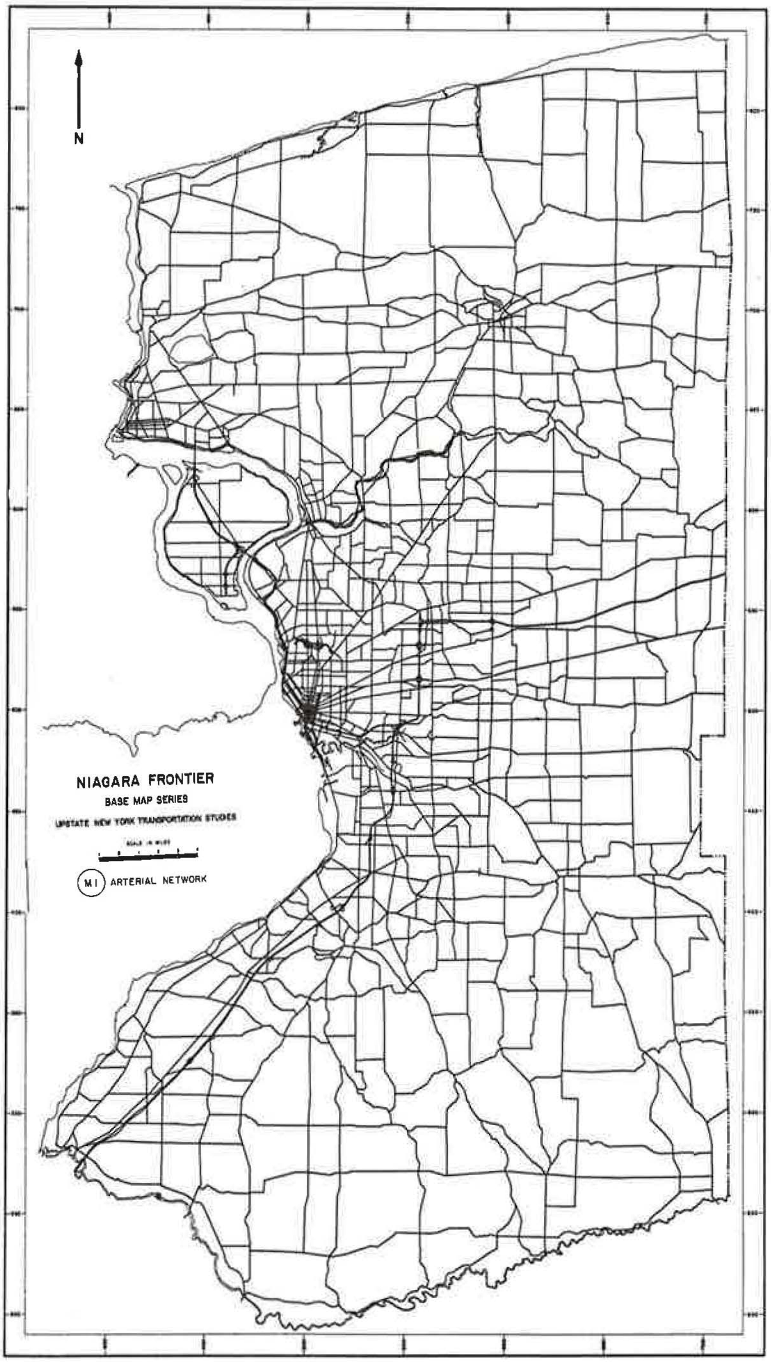


Figure 2.

Expressways and their ramps were easily identified by their geometric features (multi-lane, divided highways), access control, and type of traffic found on them. Surface streets and highways, however, were less easily identified, and it was necessary to establish criteria or characteristics for these streets to maintain consistency and accuracy. Each was considered if it had one or more of the following characteristics:

1. Major Streets
    a. Four or more traffic lanes.
    b. A total paved width of 56 ft or more.
    c. Traffic control devices and signal system that provide for preferential treatment to traffic on the street.
    d. Streets with reversible lanes.
    e. Streets with parking prohibited during peak-hour traffic.
    f. A continuously signed route (numbered or truck route).
    g. A part of a one-way couplet if arterial by other criteria.
2. Secondary Streets
    a. Any street (no matter what the design standard) if it is the only route available to through traffic.
    b. Any street which gives access to a traffic zone and which is likely to be improved within the planning period.
    c. Any artificial street which must be inserted into the system to provide access to a presently undeveloped traffic zone.

Using these definitions and principles, the existing arterial network of the Niagara Frontier was identified and delineated on a set of base maps ranging in scale from 1:4,800 in Buffalo to 1:24,000 in the rural areas.

This phase of the work required very close cooperation with officials in city, county, and state agencies. Their review and comments were essential to the determination of the existing arterial network. Identification of each arterial type was the first step of the inventory. This was accomplished by color coding each selected street or highway by type as it was posted on the base maps. The selected arterial network is shown in Figure 2.

INVENTORY AND CODING

Items Inventoried

In determining which characteristics of the network to inventory, consideration was given to two important factors: the kind of data required for traffic assignment purposes, and additional information needed for evaluating and planning improvements to the existing arterial system.

Since the coding form (Fig. 3) was designed to accommodate all the items to be inventoried, this discussion of the inventoried items is essentially a review of that form. Each item on the form falls into one of two general categories: identification, which includes map number, district, and link identification; and characteristics, which include direction, length, zoned speed, parking restrictions, width, intersection control, one- or two-way streets, area type, volume, and year volume count was made.

The items in the identification category serve as the index for the characteristics and make it possible to locate readily each individual item inventoried in the entire arterial network.

Requirements for Traffic Assignment.—The particular assignment program used by the Niagara Frontier study was based on a minimum time path routing with a capacity restraint that increased link travel time as assigned volume increased. Because the assignment of trips theoretically begins under zero volume conditions, the initial input of travel time on each link had to represent a reasonable travel time for one car to traverse the link, assuming no interference from other traffic. This travel time was defined as the free-flow time, i.e., the travel occurred under extremely low volume conditions, delayed only by fixed traffic control and the inherent features of the street design.

To determine this free-flow travel time, it was assumed that vehicles would drive at the posted speed limit (zoned speed) between intersections and that all delays along a section of arterial street would be a function of the intersections at each end of this section. Inasmuch as the selected arterial network did not include all streets and highways, the average delay time assigned to each coded intersection included also delays due to intermediate controls at uncoded intersections representing local streets not a part of the arterial network.

Field time runs were made under extremely low volume conditions (during early morning hours) over selected sections of the arterial network. From these field tests it was possible to determine the average arterial intersection delay for each link type within three different area types. The link types were those previously defined, and the area type generally corresponded to those defined in the Highway Capacity Manual (1) as downtown, intermediate, and outlying. Free-flow travel time was then calculated for each link as follows:

$$\begin{aligned} \text{F F travel time} &= 3,600\left(\frac{\text{zoned speed (mph)}}{\text{length (mi)}}\right) + \\ &\quad \tfrac{1}{2}\left(\begin{array}{c}\text{intersection delay (sec)}\\ \text{at each end of link}\end{array}\right) \\ &= \text{time (sec)} \end{aligned} \tag{1}$$

With a selected sample of travel times to determine average delays, the inventory requirements to determine travel time were length, link type, area type, and zoned speed.

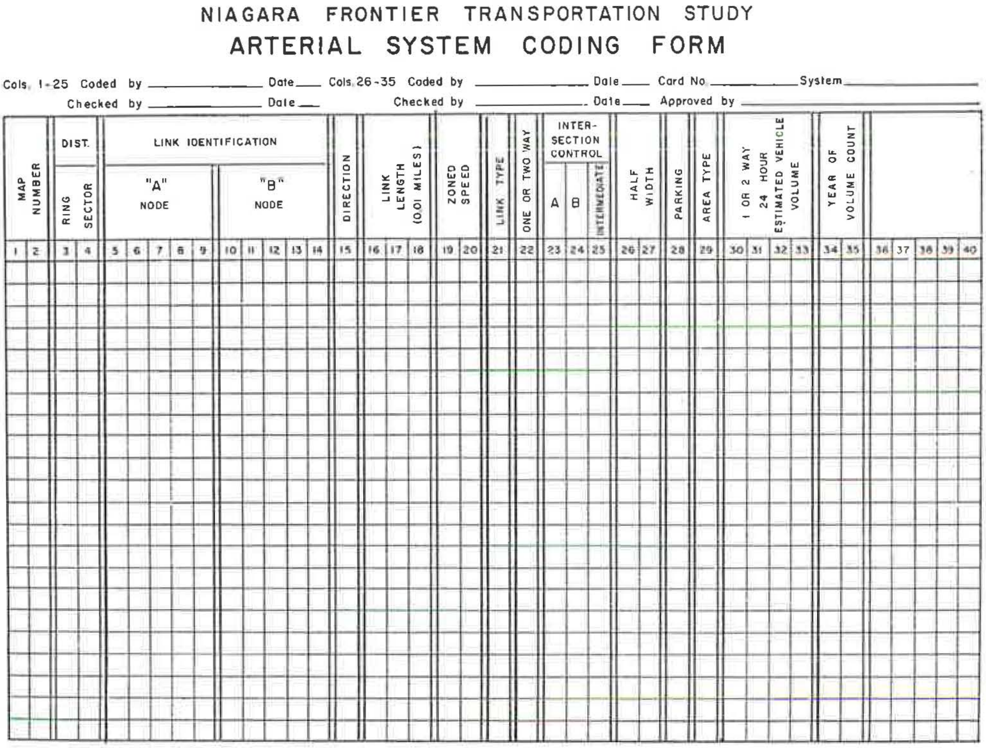
Capacity, the second required input of the assignment program, was based on revised curves (2) which immediately set the requirements for several inventory items: street width, link type, one- or two-way street, parking restrictions, area type, and intersection control. Bus stops were omitted since parking generally controlled capacity on bus routes.

Certain basic assumptions, however, were necessary before the curves could be used. The hourly volumes from the capacity curves had to be converted to average daily traffic in order to make them comparable to the assigned volumes. This was accomplished by setting the tolerable level of service during design hour at 11 percent with a 60-40 directional split. The size of the network required the use of some approximations to simplify the machine calculation of link capacities. Therefore, it was assumed that each coded intersection of surface streets in the arterial network was signalized with a 60-sec cycle and that there was approximately 20 percent turning traffic and 10 percent commercial vehicles at each.

Capacity for each intersection approach in the network could then be determined from the curves. Intersection control governed the amount of green time available; i.e., when a major and secondary link intersected, 60 percent of the green time was allocated to the major road, and 40 percent to the secondary. Controls for each of the intersection types are:

Intersecting Links	Allocation of Cycle Time (%)
Major and secondary	60-40
Major and major	50-50
Secondary and secondary	50-50
Secondary and major	40-60

Using a numeric code for the intersection control at each end of the link, the intersection controlling capacity as well as the link capacity could quickly be determined by machine sorting and processing. This method of determining capacity on surface streets was adopted to give emphasis in the assignment program to the additional capacity available on most primary streets resulting from favorable signal control and signing. This became increasingly important in a traffic assignment where a capacity restraint was used to increase link travel time as more volume was assigned to the link. Column 25 in the coding form was allocated for intermediate control, although it has not yet been used. As more inventory data become available on traffic control



NIAGARA FRONTIER TRANSPORTATION STUDY

ARTERIAL SYSTEM CODING FORM

Cols. 1-25 Coded by ______________ Date____ Cols. 26-35 Coded by ______________ Date____ Card No. __________ System __________

Checked by ______________ Date____ Checked by ______________ Date____ Approved by ______________

	DIST.		LINK IDENTIFICATION							INTER-SECTION CONTROL								
MAP NUMBER	RING	SECTOR	"A" NODE	"B" NODE	DIRECTION	LINK LENGTH (0.01 MILES)	ZONED SPEED	LINK TYPE	ONE OR TWO WAY	A	B	INTERMEDIATE	HALF WIDTH	PARKING	AREA TYPE	1 OR 2 WAY 24 HOUR ESTIMATED VEHICLE VOLUME	YEAR OF VOLUME COUNT	
1 2	3	4	5 6 7 8 9	10 11 12 13 14	15	16 17 18	19 20	21	22	23	24	25	26 27	28	29	30 31 32 33	34 35	36 37 38 39 40

Figure 3.

devices, this information will be included in the inventory and used in capacity calculations. The capacity of expressways and ramps was handled separately from the surface streets. Here it was assumed that there were no signalized intersections except for off-ramp terminals (handled as surface streets), and capacity was based on the number of lanes available.

Requirements for Planning.—It should not be inferred by the previous heading that the items inventoried to determine capacity and travel time are not important to the planning process, for they are very important. In addition to these items, however, gages must be devised to measure the use of the arterial system and determine its deficiencies. Existing volume is one gage. When used in combination with the items previously inventoried, a volume to capacity ratio can be calculated for each link and the vehicle-miles of travel can be determined for each link type and compared to the available vehicle-miles of capacity.

To determine the current existing volumes on the network all recent volume counts (and dates) taken throughout the study area were obtained from local and state highway organizations. The procedure used was to post all existing counts. These were then posted on the arterial system maps. Based on these counts the volumes were estimated on links where no counts were made and all counts were updated to 1962 by annual expansion factors for each base year. Since the annual expansion factors used for each year were constant for each link type, it was only necessary to inventory the volume and the year the volume count was made. (This resulted in an approximate volume count which is currently being revised by a counting program.)

Organization of Work

To organize the work of inventorying and coding a large arterial network efficiently, the entire operation had to be thought of as a system with inputs and outputs. The input to the system consisted of three basic items: arterial network maps, the physical

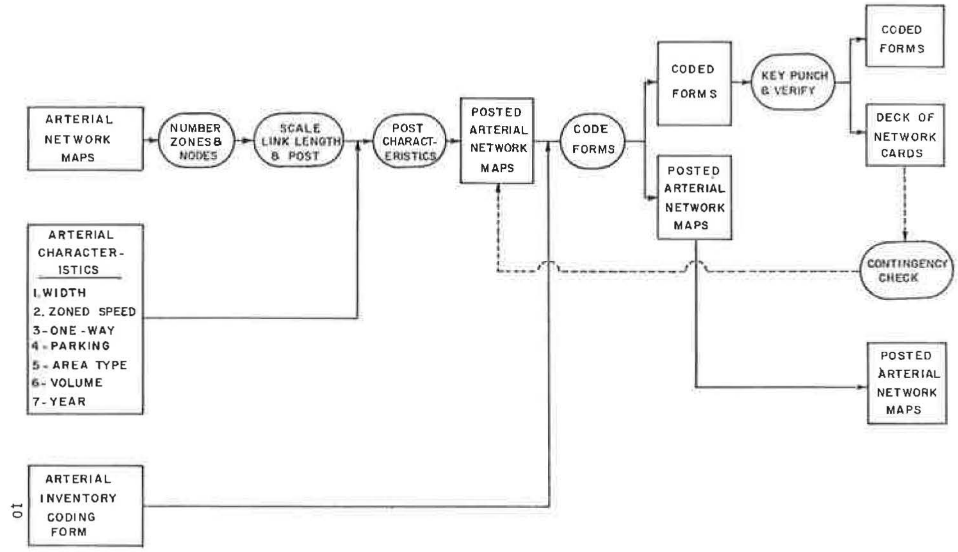
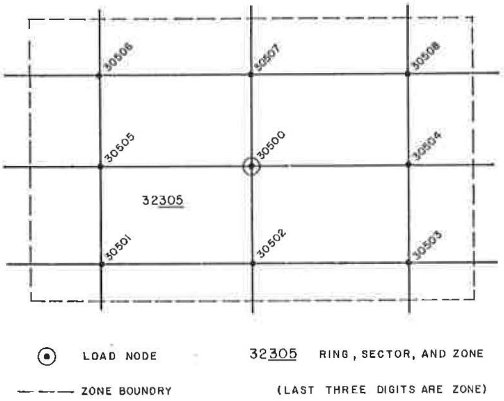


Figure 4. Arterial system coding operation.

and traffic characteristics of the network, and coding forms. The desired output from the system was: a deck of cards which described the network for computer assignment and which could be used also for summarizing all inventory data for planning purposes; and a set of posted arterial network maps which described the coded network. A block diagram (Fig. 4) describes this entire operation from the initial input of data to the final output. All succeeding techniques used to perform the system operations were developed to minimize field work since the survey was designed essentially as a paper inventory.

Coding Techniques

Node Numbering.—Once defined, the arterial network had to be described in a form usable by electronic computers and other high-speed data processing machines. Each intersection in the arterial network, therefore, was assigned a 5-digit identification or node number. For ease in locating specific intersections, the first three digits of each node number corresponded to the traffic zone in which the node was located, and the last two digits represented the number of that node within the zone. To identify the load node or centroid in each zone, the last two digits of this node were always designated 00 and the remaining nodes numbered from 01 to 99. The use of a 5-digit node number greatly speeds coding and, later, plotting work. Five-digit nodes can be mechanically converted to a 4-digit computer numbering system. The overall savings in time are substantial. A typical section of the numbered network is shown in Figure 5. The dashed lines represent zone boundaries, and the large bold numerals the number of the ring, sector and traffic zone.



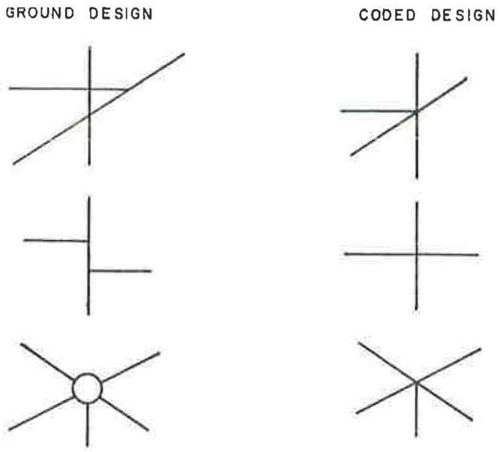


Figure 6.

Usually in any traffic assignment program there is an upper limit to the number of nodes that can be used to describe any one network. Therefore, to conserve on node numbers used in the network, staggered street intersections which fell within 200 ft of each other were considered to be at the same point with all links emanating from one node. Examples of this are shown in Figure 6.

A log of nodes used was kept to insure that the maximum number would not be exceeded and to avoid any duplication of numbers within the network.

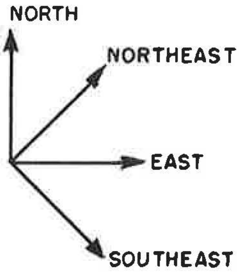
Compared to past procedures where blocks of node numbers were reserved for each map to provide a means of locating nodes. This method of node numbering proved very satisfactory during the inventory. Coders and others not too familiar with the network had no problem in finding specific links or intersections. To add a node to a map was accomplished by looking at the node log to obtain the next unassigned node number in the zone in which node was located. Since there are 100 node numbers available in each zone, it will not be necessary to reuse numbers deleted from a previous network when updating or modifying a network.

Posting.—The inventory items were posted on a set of arterial network maps to provide a common source for the items to be inventoried and to identify quickly the link on which each item was located. Since the map number, ring, sector, and zone boundaries, link identification, and link type were previously delineated on each map, posting involved recording the length, zoned speed, one- or two-way traffic, half pavement width, parking restrictions, area type, 24-hr volume, and year of volume count for each link of the network.

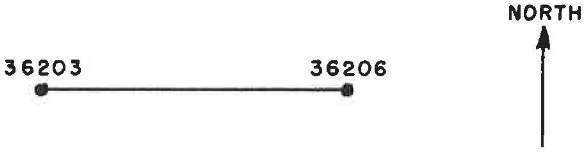
Length was scaled directly from the maps with specially prepared scales which read miles directly to the nearest 0.01 mi. Zoned speeds, obtained from tabulations of legal speed limits prepared by the New York State Traffic Commission, were posted in miles per hour. In instances where a speed changed within the limits of a link, a weighted average was used. One-way streets were indicated by a directional arrow in the direction of traffic flow. No arrows were used for two-way streets. Half street width for each link represented the curb-to-curb pavement width divided by two. In determining this width, any median areas or other permanent barriers which reduced the usable curb-to-curb pavement were subtracted. On links of variable width the least half width was posted since this would be one of the controlling factors in calculating capacity.

Parking regulations were posted in only one of two ways on each link. Either parking was permitted (P) on the entire length of link, or it was prohibited (NP) on the entire link. In cases where parking regulations varied during the course of the day, those regulations which governed during peak periods of traffic and appreciably affected capacity were posted. Area type was posted as either downtown, intermediate, or outlying and was generally on a zone basis. When available, 24-hr vehicle volume counts and the date the count was made were posted on each link. The best possible estimate was then made for the remainder of the links from the known counts on adjacent links. Direction and intersection control were not posted on the maps. Direction was a coding convention, and intersection control was determined from the types of intersecting links at each node.

Directional Conventions.—Certain conventions were adopted to simplify the coding of links and to put the data in a form suitable for the traffic assignment program used. Links were only coded in the specified grid directions, as follows:



The node from which the links to be coded emanate was designated the A node. The nodes at the opposite ends of the links were designated B nodes. All links were then coded from A to B in the specified grid directions, for example:



Numbers 36203 and 36206 identify the nodes of a link. This link would be coded in an easterly direction 36203 to 36206, making 36203 the A node and 36206 the B node. This convention provided the coders with a logical procedure to follow in coding the network and provided the inventory with a directional index of the network.

The only exception to these instructions was made in the case of one-way links. These links were always coded with the A to B node convention representing the actual direction of traffic flow on the link. This enabled the computer program to assign traffic in the proper direction on streets coded as one-way. Because no direction code was designated for south, southwest, west, and northwest grid directions, these directions used the respective code for their 180 degree complement.

Link Location.—As previously stated, the first three digits of each node number represent the zone in which the node is located. Therefore, for purposes of summarizing link data and keeping track of the links coded in each zone, a link was assumed to fall within the zone in which the A node was located. Although there were many instances where links were located within two or more zones, the above convention was adhered to and proved very satisfactory for the summarization of inventory data by traffic zone.

Expressways.—Unlike surface arterials (major and secondary streets) which were generally coded as two-way streets, all expressways were coded with one-way links. In the following example, 24301, 24302, 24303, and 24304 are nodes.

The first link was coded according to the direction from node 24303 to 24301 and the second from node 24302 to 24304. Although they are in opposite directions, each link received the same direction code. Street width on expressways was considered as 12 times the number of lanes, assuming that for practical purposes all the expressways inventoried had 12-ft lanes.

Interchange Ramp Coding Design.—Each connector between a surface street and an expressway was designated as a ramp, either one-way or two-way. One-way ramps were delineated with directional arrows in the same manner as surface streets and expressways. Ramps were coded in either of two ways: as they actually existed on the ground or by an abbreviated coding design. Generally all ramps were coded as they existed if maps of sufficient scale were available so that link lengths could be determined. If, however, adequate maps were not available, then an abbreviated coding design was used.

As constructed on the ground, the interchange in Figure 7 is a conventional cloverleaf. The simplified coding design provides for each of the eight individual turning movements of the interchange and requires much less coding. To determine the link length for each ramp, assume that a direct movement is made on a short ramp and an indirect movement on a long ramp of the interchange. The length of a short ramp was then considered equal to the distance from the street node to which the ramp was connected to a point midway on the bridge of the cross-street. For example on the sketch of the coding design, AB and DC are short ramps representing direct movements, B and D the street nodes, and E a point midway on the bridge of the cross-street. Therefore, the short ramps were coded so that AB = BE and DC = DE in lengths.

The length of a long ramp was considered equal to the distance between the street node to which the ramp was connected to a point midway on the bridge of the cross-street plus 0.1 mi for the indirectness of the movement. Using the same example as above, AD and BC are long ramps. Therefore, the lengths of the long ramps were coded as AD = DE + 0.1 mi and BC = BE + 0.1 mi.

Coding Overlays.--To insure that no links were omitted or duplicated during the coding of the arterial network, each posted map was covered with a vellum paper overlay. As each link was coded on the arterial coding form it was recorded on the overlay by tracing over that particular link with a pencil. The overlay then became a graphic index of the coded links and provided the coders with a visual means of checking which links had been coded. These overlays became significantly more important as the number of coders increased and the work of each overlapped.

Coding Operation

Coding.—Using the techniques previously described, each item on the coding form was coded for every link in the arterial network. In a network as large as that of the Niagara Frontier it was essential to set up simple bookkeeping procedures (in addition to coding overlays) to prevent duplication and omissions in the network coding. The method devised was to record the number of each zone to be coded on a coding form and to file this set of forms by district groupings. Once the coding operation was under

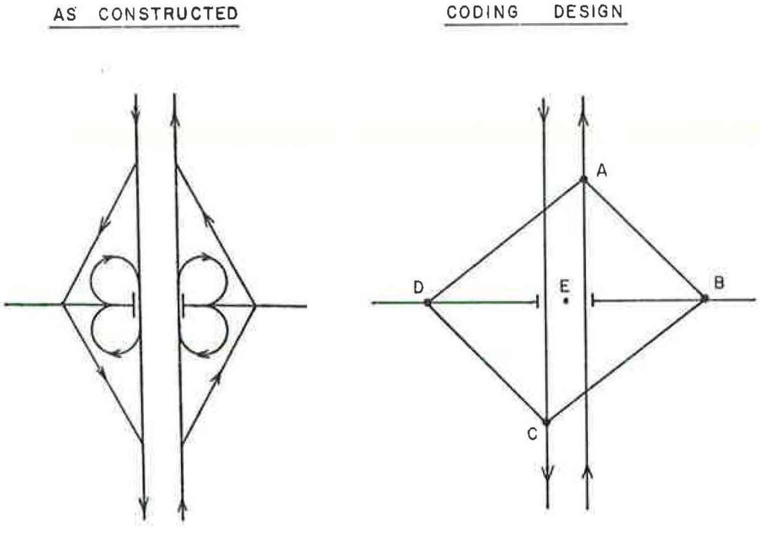


Figure 7.

way, each coder would go to this file and obtain the form(s) for the zone(s) he was assigned to code. If additional forms were required for a particular zone, the zone number was entered on each subsequent form and it was numbered 2 of 3, etc.

On completion of coding in a zone, the coder then placed the completed form in a separate file maintained for completed but unchecked forms and proceeded with the coding of links within another zone. Each of the coded forms was subsequently checked by a different coder and placed in a "completed" file to await keypunching. A separate log (by traffic zone) was then maintained for all forms sent to the data processing section for keypunching so that the exact location of all coded information was known at all times.

Coding Corrections.—Coding corrections were basically of two types: those found during the coding and keypunching operations and those found after the contingency checks were performed on the coded data. In each case a few simple rules sufficed to insure that corrections were properly carried out.

1. General.—Under no circumstances were additional links placed on a coding form once it was logged out for keypunching.

2. Corrections to Previously Coded or Keypunched Links.—The corrected link was entered on a new coding form with the zone number and the word "Corrections" written in the upper left corner. The original coding form with the incorrectly coded link was then located and crossed out. If the link had already been keypunched, the incorrect card was located and destroyed.

3. Corrections Subsequent to Contingency Checks.—These corrections were handled in much the same manner. The errors were listed as the contingency checks were run and the necessary corrections coded on new forms. The link cards in error were then located and destroyed and replaced with the cards keypunched from the coded corrections.

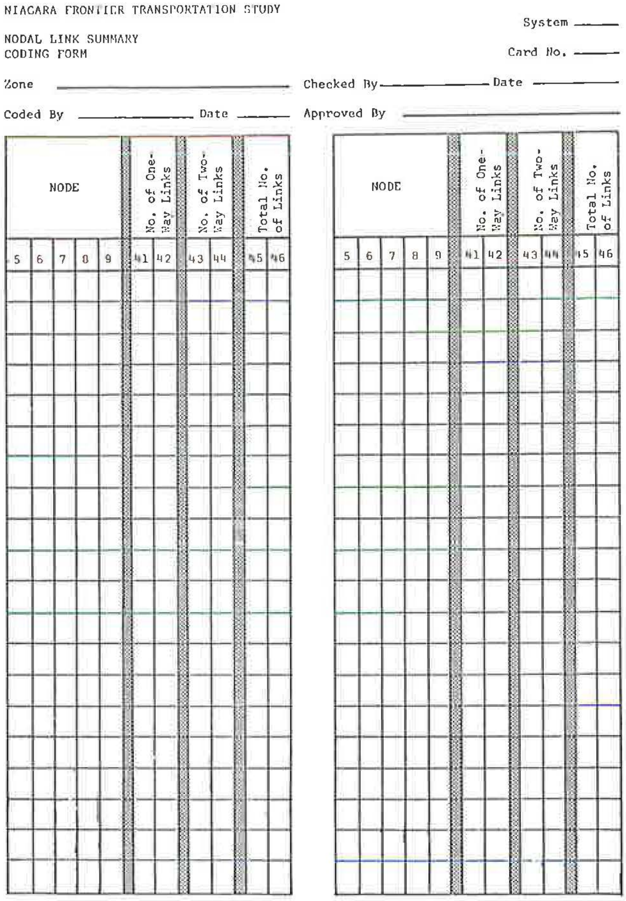
Network Revisions.—The network coding had to be flexible so that revisions or modifications could be made for subsequent traffic assignments. This revision or updating of one network to another can be handled in much the same manner as corrections and additions to the existing arterial network were accomplished. These techniques must, however, be supplemented so that a positive record is kept for each network tested and so that there will be no confusion in going from one network to another. This can be easily accomplished by filing a duplicate deck of network cards and a set of posting maps.

Once the geometrics of a proposed network have been developed, they must be incorporated into the previous system. This can be accomplished by first delineating the proposed changes on an overlay of the existing network, which immediately points out the links in the present network that must be deleted. These deletions, including link identification and location, should be coded on the coding form in columns 1-14. From this record a set of revised arterial network maps can be prepared, deleting the portions of the previous network no longer required and including the proposed modifications. All nodes that are required to describe the revised geometrics are then located and numbered. The node numbers used in each zone in updating a network should begin with the next highest number that was used in the previous network.

After posting all required data on the revised arterial maps the changes in the network should be coded using the same procedures previously developed. To complete the updating operation the coding forms containing the deletions and additions to the network should be sent to the data processing section where the deleted link cards will be removed from the network deck and the new links keypunched and added. All work should be fully documented and the bookkeeping methods used in coding the original system should be used.

Contingency Checks

Contingency checks were performed on all coded and calculated items in the arterial inventory. To insure the accuracy of the coding, single-field and multiple-field checks were set up for all coded data. These checks included comparison for impossible codes, values above or below allowable limits, or multiple-field combinations that were not allowable.



NIAGARA FRONTIER TRANSPORTATION STUDY

NODAL LINK SUMMARY
CODING FORM

System ____

Card No. ____

Zone ____ Checked By ____ Date ____

Coded By ____ Date ____ Approved By ____

NODE					No. of One-Way Links		No. of Two-Way Links		Total No. of Links	
5	6	7	8	9	41	42	43	44	45	46

NODE					No. of One-Way Links		No. of Two-Way Links		Total No. of Links	
5	6	7	8	9	41	42	43	44	45	46

Figure 8.

Other contingency checks were set up for all calculated inventory items. These checks were not made to check the accuracy of machine calculations, but to find incompatible combinations that slipped through the coding operation. For example, the assignment program used had a maximum allowable value for travel time on a link and even though safeguards were built into the coding instructions to prevent exceeding this value, it was still possible for a coder to code inadvertently a link length and zoned speed combination which would pass the contingency checks for coding but give a value exceeding the allowable maximum. Contingency checks for each of the calculated values were, therefore, established to eliminate these errors.

In addition, a "zero balance" check was performed to insure the completeness of the coded network since this is the most essential requirement of the traffic assignment program. To perform this check the deck of network inventory cards was reproduced with the A and B nodes reversed. This deck was then merged with the original deck and the cards sorted in sequence on the A node. This permitted a machine summary to be made of the number of links emanating from each node. This nodal link summary was then mechanically compared to a manual count of the number of links at each node (coded on Form 130.2, nodal link summary, Fig. 8) punched into a separate deck. If the difference in the number of links at each node from both sources did not equal zero, the coded network was checked to determine if the network coding was incorrect or the manual count was incorrect. Using this procedure all missing or duplicate links in the arterial system were found, thus eliminating program stops during traffic assignments.

MANPOWER REQUIREMENTS

The Niagara Frontier arterial network inventory and coding operation required approximately two months to complete and was accomplished with six coders and one coding supervisor. At the end of this period some 3,900 miles of arterial streets and highways had been inventoried and described in numeric form by 2,020 nodes and 3,330 links. To provide a basis for estimating manpower and time requirements for future inventories of this type, a record was kept for each significant phase of the operation. Excluding the time required to determine the arterial system (which was done by professional personnel), the inventory and coding required a total of 1,546 man-hours. This total time can be broken down into three phases: zone and node numbering, posting inventory data, and coding. The actual time required for each of these phases was as follows:

Operation Phase	Man-Hours
Zone and node numbering	105
Posting inventory data	625
Coding	816
Total	1,546

For estimating purposes the man-hours must be related to the size of the network inventoried. Because the number of nodes used to describe a network bears a direct relationship to network size, the node has been adopted as a standard unit and all time reduced to the man-hour requirements per node. The man-hour requirements for each node in the network are as follows:

Operation Phase	Man-Hours per Node
Zone and node numbering	0.052
Posting inventory data	0.309
Coding	0.404
Total operation	0.765

Applying these man-hour rates to the number of nodes in a future network to be inventoried should provide a good basis for estimating the time and manpower required to complete the survey.

IMPLICATIONS

There are many benefits to be gained from the symbolic representation of a detailed inventory of a regional transportation network. This is especially true where the network representation can be assembled in the memory of a high-speed computer which provides, in effect, a simulation or operating model of the actual network itself. Some of the remarkable possibilities are presented in the following:

1. Performance characteristics of the actual network can be assembled and summarized at high speeds. With current link volumes included in the inventory, vehicle-miles of travel can be summarized by link type and by geographic location. Analyses of the spatial characteristics of overloads and excess capacity by type of facility can be programmed. Other characteristics such as the pattern of parking restrictions, intersection controls, and speed regulations, can be assembled, cross-tabulated, and analyzed in minutes instead of the days required to make a field inspection.
2. A better understanding and testing of network performance is possible. Relationships between characteristics of the network can be analyzed and tested to obtain a

better idea of how networks perform. The impact of intersection control on free speed, the relationship of speed to congestion, and the impact of turning movements on both speed and capacity are typical areas where additional research is needed.

3. More realistic assignments are possible. The inclusion of all arterial streets in the network to which traffic is assigned was a significant improvement over previous assignment routines. With better understanding of network performance with respect to capacity, speed, turns, etc., better assignment techniques can be devised. Studies of route choice, optimum zone size, highly detailed assignment requirements for special cases such as redevelopment areas and central business districts will provide a better basis for designing assignment programs.

4. Better testing and evaluation of plans are possible with improved assignment techniques. With faster and more accurate and detailed assignment techniques, better evaluation of proposed plans is possible. The cost of travel over a network, based on operating costs, accident costs, and personal time costs, is a powerful tool in measuring relative performance of different network plans. Additional refinement of these cost factors will improve the ability to discriminate between plans. With improved assignment techniques and especially with the high speed-low cost aspect of computer assignment, the question of scheduling of planned improvements seems ripe for analysis and programming.

In addition to the advantages gained in traffic assignment and the summary and review of network data, many implications can be drawn from the use of this numeric form of inventory for the arterial network. Through the use of simple coding procedures the arterial network can be related to the land-use survey, provide a means of sampling the vehicle-miles of travel over the network, serve as a base for mass transit (bus and rail) studies, and be used to inventory all data related to streets and highways. The use of similar coding techniques may also have application in the study and assignment of rail travel and the movement of goods.

Relating the Arterial System to Land Use

The land use along each arterial street can be related to the coded network by simply cross indexing the two surveys. Land use in a study area can be coded by block face to each street by giving each street and each block a numeric code. By using a block numbering system based on an X-Y grid coordinate system and by adopting a directional coding convention for the network so that the X-Y coordinates always increase in the direction the link is coded, the land use for each block face fronting on the arterials can easily be summarized for each link in the network. This is accomplished by matching the network card deck and the land-use deck on block number within street code.

A wealth of information may be obtained from the land-use and arterial relationship.

1. The land fronting on each type of arterial can be summarized to determine if certain arterial types generate predominant land uses.
2. The sphere of influence of an expressway on the land use in an area may be determined through the study of successive land-use band widths on either side of the expressway.
3. Intersection types can be reviewed to ascertain if particular land uses are peculiar to intersections of the same type.

In the study of alternate locations for a route, a detailed study can be made quickly of the type and amount of land that will be displaced by each alternate route. In fact, if the appraised evaluation of each land-use parcel can be obtained from assessor's records, these values can be coded and the loss in the tax base determined for each route. In addition, within the assumption that the assessed evaluation is a function of market value, an estimated right-of-way cost could be calculated from the land-use information for alternate route locations. Moreover, couple this knowledge with the use of high-speed computers, and a means is available to determine what savings, if any, could be attained by shifting the alignment of a proposed alternate within specified locational restrictions through a corridor.

Sampling Vehicle-Miles of Travel

Using the street code and link identification, it is also possible to separate all arterial streets from local streets by machine processing. This technique is very useful in establishing sampling procedures for vehicle volume counts to determine vehicle-miles of travel over the local and arterial streets. For local streets, the sample can be selected on the basis of the coded block faces used in the land-use survey. The address of each sample location can be readily found from the block coordinates and street code.

To sample arterial street travel the sample may be selected either by link or node. For example, if it is decided to take intersection counts at every fifth intersection, the sample would be machine selected from the total number of nodes. The street address of each intersection could then be determined from the street code of the links emanating from the node. If it is decided to sample links and count at midblock locations, the sample can be selected in the same manner and the link identified by street name and the names of the intersecting streets at both ends. This sampling procedure for travel on local and arterial streets not only makes it possible to take a better statistical sample through machine processing but also saves much time in determining the street addresses required to locate the count stations in the field.

The method is particularly useful in scheduling a short-count program to determine travel volumes. A sample of intersection locations could be determined and short counts made at each station. If the approach volumes at each intersection are counted for each turning movement, the volume on each link emanating from the intersection node can be summarized by machine through use of adjacent node numbers to identify individual movements. The short counts can then be expanded to 24-hr or average annual daily traffic through machine processing by relating the short counts to control station counts. Since the ultimate goal of a counting program is to determine the volume of traffic on each link of the network, the selected sample can be analyzed for turning movements by intersection type and relationships developed to extrapolate the sample counts to the remainder of the network.

Mass Transit and Railroad Studies

Although primarily developed for the inventory and coding of a highway network, the same techniques may be applied to mass transit lines and urban freight railroads. At the time the arterial network is coded the links which are utilized as bus routes (including local streets) can be given an identifying code and subsequently separated from the highway network for transit assignments. A transit network derived by this method would have to be modified slightly to meet its own special needs, such as additional load nodes along the system to account for pickup and discharge of passengers, the insertion of transfer points to permit changing from one bus route to another, and the use of turn prohibitors to eliminate impossible trips which might occur (not part of regular scheduled bus route) due to favorable time on transfer links. The rail system would require development of similar coding techniques such as transfer points and turn prohibitors but the same numeric coding system to identify links could be used throughout.

Of course, the real research problem is to determine how much the choice of mode of travel is a function of the alternative networks and how much is a function of factors such as car ownership, demographic characteristics, and other factors. If it is possible to segregate the auto-using only population from the transit-using only population, then it would be possible to allow the network performance itself to determine the mode split for the remaining population. To the extent that this is a large proportion, this would not only greatly facilitate the process of assigning travel but would also represent a significant improvement on present assignment techniques as related to mode of travel. With present techniques, each mode is generally segregated and assigned separately to its own particular network.

Inventorying Data Related to Streets and Highways

The numeric coding system for describing the arterial network also provides an excellent base for inventorying all data related to streets and highways. Although this paper has primarily stressed the use of the system to inventory and code for traffic assignment purposes, it should be pointed out that items such as lighting, parking meters, traffic control signs, traffic signals, and other related information can readily be inventoried and stored for future reference using this inventory and coding technique. With few modifications it would be possible (by using street name codes and number addresses) accurately to locate by street address the items previously listed. Moreover, if a street and highway system is inventoried and coded in sufficient detail, i.e., both local and arterial streets for the entire study area, it would be possible to select an arterial system based on a given set of criteria by machine processing. This would perhaps eliminate much of the subjectivity that has been experienced in the past when defining an arterial network for a study area.

SUMMARY

The implications of numeric coding for an arterial network are just now beginning to be investigated. From the foregoing it can easily be seen how many of the surveys made during the course of a transportation study can be integrated through numeric coding which also provides a basis for storage of information in a data bank. The availability of high-speed data processing machines provides a relatively low-cost method of directly comparing the data of one survey to another and permits ready access to individual items stored in the data bank.

While this paper has stressed the use of numeric coding primarily for traffic assignment, the implications drawn from the technique point out many areas for further research: the determination of vehicle volumes on each link in a network based on a selected sample of short counts, the integration of several modes of travel into one overall assignment, and the simulation of actual operating conditions on a network based on the characteristics inventoried.

The Upstate New York Transportation Studies (UNYTS), as a continuing study, will refine or develop and use many of the methods briefly discussed. Many other additional uses will undoubtedly be found as new and different approaches are developed to study the urban transportation problem.

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