A Technique of Highway Coding for Route Recognition and Position Description

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This paper reports a machine-adaptable technique for the non-ambiguous designation of a vehicle's exact position within a system of roads as well as a selected route to proceed to any other point in the system. This technique can be used to address location and vehicles for any highway communication application.

The technique needs only to be supported by a method for node designation in order to provide (a) a machine language for record keeping; (b) a mathematical tool to use in traffic control and assignment problems, and the discrete address of all vehicles in any application of communications; (c) a machine language for route following which will allow development of this important driving aid; and (d) a manual-visual method for route following which may be implemented almost immediately. The technique is illustrated by using a simple node designation method for a limited network and a prepared route selection matrix.

•THIS paper describes some of the results obtained on a recently completed study of route coding and recognition techniques. Assuming that effective measures of preference can be developed and assigned to each branch of a network, there remains a prior need to establish the framework and rules for incorporating these parameters into a working highway transportation system. Addressing this problem, a procedure was developed by which the "best" route between any origin and any destination can be calculated and identified by an appropriate sequence of numbers. At each node, or intersection, the operator, or vehicle, can determine which branch is integral to the "best" route by recognizing one of a very small set of numbers. Recognition is simplified by previous knowledge that the desired destination is one of the many toward which this branch will lead. This approach effectively reduces the total time-bandwidth product and equipment complexity.

EXPLANATION OF TECHNIQUE

Many types of code were considered before selecting the specific technique which will be described. The principal considerations used in this selection were: (a) non-ambiguous designation; (b) minimum time-bandwidth product required for direction to follow route; (c) machine-language adaptability; and (d) simplicity.

One of the first codes to be considered was the present system of highway route numbers. This is a good system and has served the motorist well, but it does have some faults. First, there are many ambiguities. A large bandwidth, or time, is required to give route directions. Machine-language adaptability is poor.

There had to be a better way, so geographic grids were investigated. These were fine for location, nonambiguous and simple, but there was no method for giving the types of route direction required. The grid system also required a great deal of in-

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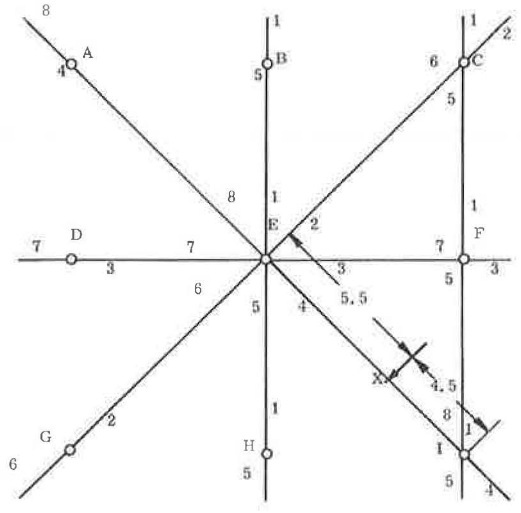

Figure 1. Location of X is E4-5.5 or I8-4.5 depending on normal travel direction.

formation to describe a location. Most of the problems were caused by a lack of identification with the highways.

Next to be considered were the numerical codes. The principal codes in this category are the telephone code and the Post Office "Zip" code. Both of these codes have serious faults. One has sufficient detail, but no geographic significance, the other has geographic significance but not enough detail. However, the research program is not over and some numerical code may be used for naming nodes.

The progress of the program led toward a nodal system. It can be based on the highway, is adaptable to machine language, lends itself to computation, is relatively versatile, and can be made nonambiguous.

But what about route direction? There is nothing in an ordinary nodal system to simplify these instructions. This is the point where a breakthrough was needed, and was accomplished.

Figure 1 illustrates the situation. Ordinarily the path between, say, I and C would be described as IF-FC, IE-EC, or one of the other possibilities. This looks simple enough, but I, E, F, and C all will be multi-character names in a system which must cover the United States. In fact, it appears that these node names must contain five alphanumeric characters to provide the detail required in order to name all the nodal points.

Therefore, "branch designators" were devised. They will be described later, but Figure 1 shows that the branches have been assigned a number of 1 through 8. Thus route direction at any node may be communicated by these numbers. For example, GE becomes G2, and note that EG is E6. Therefore route direction may be reduced to one of an eight-number set.

Position description is also quite simple. The point X moving from E to I is described as E4-5.5 where 5.5 is the number of units (perhaps miles) from E to X. Moving from I to E, X becomes I8-4.5. This method provides a simple, nonambiguous description of the position X and the travel direction if a vehicle position is described, or one side of the highway if highway location is being described.

PROJECTED ROUTE-FOLLOWING SYSTEM OPERATION

To illustrate the coding procedure and the operational features of an automatic route-following system, suppose that every block of every road in the nation is assigned an unambiguous destination code (or name) and that these are on file and accessible in some way to any driver. Because the driver must know the name of any desired destination, a capacity for "look up" is provided, whether it be in the form of a destination code book, a coded map, or a computer memory that can be interrogated by telephone.

This futuristic driver "looks up" the designation for his desired destination and, after balloting his passengers, decides what criterion of travel to select. The vote may favor the most scenic, the least cost, the minimum travel-time route or any other criteria. After choosing his criterion of travel and his destination, the driver inserts this information into his vehicle receiving equipment by dials or push buttons, and starts driving in any direction. As he approaches the first intersection or decision point, the driver/vehicle combination receives the route instructions that put him on the best, i.e., minimum cost, most scenic, etc., route to his destination. This happens regardless of his starting point or initial direction of travel, even if it is diametrically opposite to the "best" path direction.

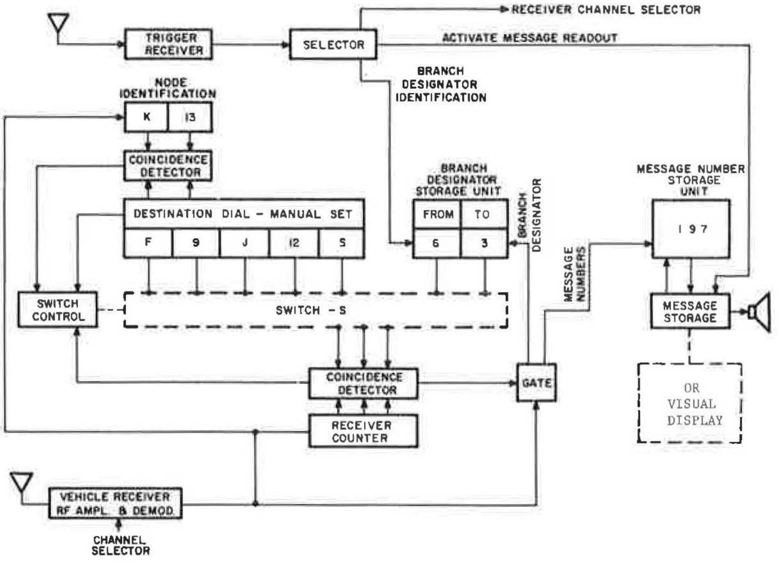

Figure 2. Simplified block diagram of a complete receiver for vehicle.

For the remainder of his trip, this driver/vehicle combination receives only those route instructions pertinent to his achieving the selected destination according to his choice of travel criteria. As part of the same message format, of course, priority information may be received that indicates local or upstream emergency conditions with auxiliary pre-programmed messages on a secondary priority basis. Instructions are made available by roadside transmitters, at or near each decision point or intersection, which continuously broadcast a sequence of branch designators—one designator for each destination in the appropriate time slot. The vehicle receiver is keyed on at the correct position and receives a start pulse and a synchronization pulse to begin counting. As the vehicular equipment counts time slots, it eventually comes to the one corresponding to the time position of the preset destination. When this count is reached, the branch designator assigned to that destination is switched into the message selection circuits which, in turn, cause the proper instruction, in English text, for example, to be transmitted to the driver.

CHARACTERISTICS OF SYSTEM

Actual design parameters were considered only to the extent necessary to develop measures of practicality. It is likely that a more careful and detailed examination of design parameters will reveal that present estimates are pessimistic.

Passive vs Active

Further debate on the pros and cons of an "active" vs a "passive" method of vehicle implementation is expected. Although this has little bearing on the basic goals as set forth for the program, some consideration was given to the question of whether the vehicle should be caused to identify its desired destination to a roadside station wherein the roadside transmitter need only transmit information concerning a particular branch designator. Although the transmission bandwidth and the complexity of the vehicular-contained electronics equipment could be reduced, the roadside electronics and many operational features would become excessively complex. For these reasons, only those results pertinent to the relatively "passive" method are described; i.e., the vehicular equipment acts only as receiving equipment to select information pertinent to manually prescribed destinations.

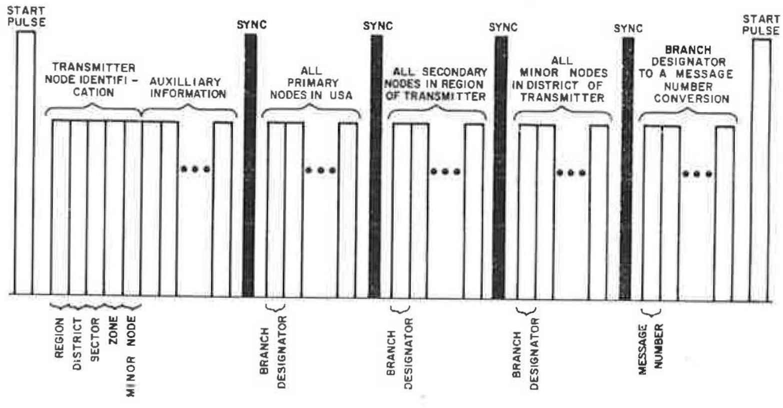

Figure 3. Node transmitter waveform.

Bandwidth and Equipment Requirements

The highway network comprised of the Interstate highways, the limited-access highways and most primary highways contains about 30,000 nodes. Calling each node a destination and using a binary representation for branch designation would require 30 to 90 kc to instrument this network. Of course, the in-vehicle destination selector will be equipped with a higher order alphabet to shorten the destination name and to ease the manual operation of selection.

Equipment complexity is greatly reduced by pre-organization of the branch numbers in time slots corresponding to the ordered arrangement of destinations. With this approach, the vehicle decision equipment is reduced to the simplicity of counters and comparators (Fig. 2).

As an illustration (Fig. 3), the transmitter might emit a start pulse followed by a waveform consisting of five major intervals separated from one another by synchronizing pulses. Intermediate to each of the sync pulses are a prespecified number of time slots that correspond to the primary, secondary, and minor nodes appropriate to the preselected destination. Finally, the message number from each transmitter which actually selects the proper one of the in-vehicle stored messages is always transmitted in the same slot relative to the sync pulse and is gated into the message number storage

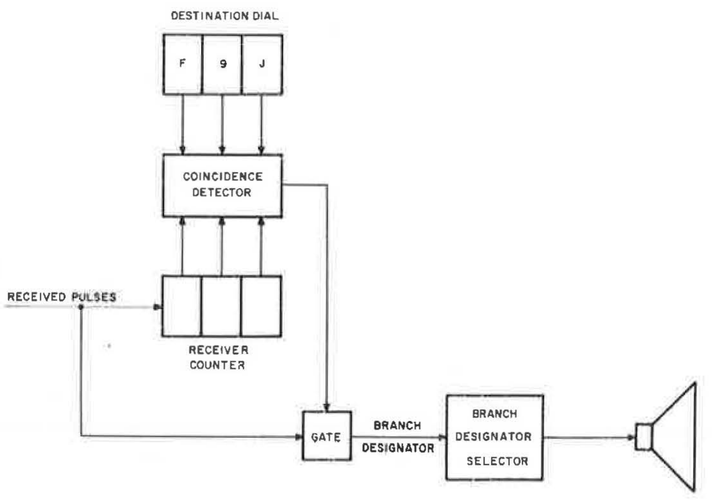

Figure 4. Simplified receiver representation.

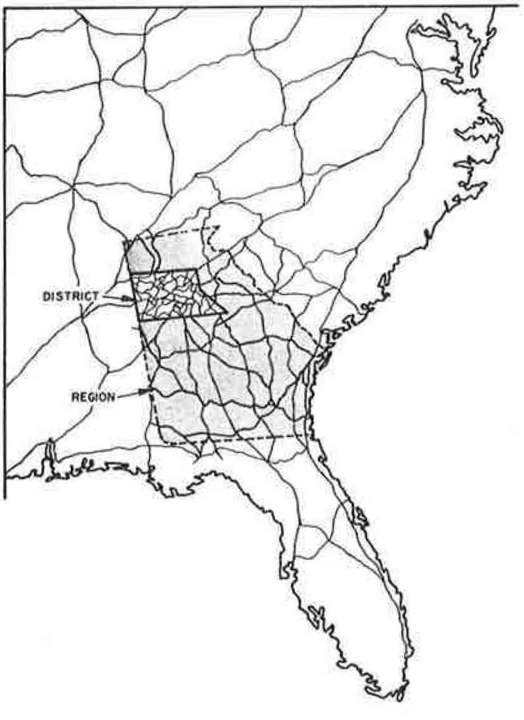

Figure 5. Highway network illustrating advanced system philosophy.

unit. This multi-level decision method of operation effects a large savings in bandwidth requirements. The current and planned road and highway network of the continental United States will contain approximately 4.5 million intersections or "destinations." Every transmitter transmitting branch designators for every possible destination would require something on the order of 12 megacycles of bandwidth to implement the system. By partitioning into "regions" and "districts," and using a multi-level decision technique, the complete system could be implemented with a bandwidth allocation of less than one megacycle.

Even a first cut at the design of roadside and vehicular equipment indicates that implementation should be simple electronically. The vehicular equipment is likely to be operationally more complex than the roadside equipment, but even so should be relatively inexpensive, as can be realized by considering the simplified block diagram of Figure 4. This receiver will accommodate a system comprised of "primary node" transmitters. Most of the necessary operations are performed in binary logic which, with integrated circuits and the advent of MOS (metal oxide semiconductor), continues to decrease in both engineering and material costs. These factors encourage consideration of "route coding and recognition" as a practical tool for improving the efficiency and safety of travel on the highways.

METHOD OF SYSTEM IMPLEMENTATION

Feasibility of the route coding and recognition procedure is further demonstrated by its capacity for evolutionary implementation. Without ambiguities, or duplication of effort, the total street and highway network can be instrumented on a piecemeal basis. Consider, for example, Figure 5, which represents three different degrees of instrumentation (assuming that each line is an instrumented highway). That portion labeled "District" indicates extensive instrumentation of minor and secondary routes superimposed upon an instrumented major highway network. Any other area, even one entirely disjoined from an instrumented area, can be instrumented to be completely compatible with the rest of the system. Thus, as the traveler leaves an instrumented section, he no longer receives "best route" information until he again enters a portion of the network that is instrumented. At that time, without re-selecting his destination, the "best route" signals are again automatically processed to give proper directions.

Another facet of system implementation is exhibited by a slightly different interpretation of Figure 5. Suppose that only that part of the United States depicted in the figure is instrumented but that in this whole section all minor, secondary, and major highways are instrumented. Someone leaving, say, Seattle, Washington, with a destination within the area shown as a "District" will choose his own route, probably on the Interstate, until he enters the area depicted by Figure 5. Then he will begin to receive signals only from primary transmitters that direct him toward the "Region" which contains the "District" to which he is headed. As he enters the "Region," he begins receiving signals from the secondary transmitters, as well, until he finally enters the

"District" when he receives signals from every transmitter involved in his "best route." Notice that with a hierarchy of transmitters used in this way a finer and finer resolution of the network can be effected as the vehicle approaches its destination. This design philosophy can be adopted to reduce the expected complexity of system implementation.

ESTABLISHING COMPLETE DESTINATION FILE

The next step which must be taken to establish a route code is the selection of an orderly system for "naming" the nodes. This may be done so that the names have geographic significance, or so that present route numbering is preserved. Some combination which will allow an orderly transition is certainly desirable. Mathematically the names (probably numbers) may be completely arbitrary.

After selecting a system for naming the nodes, a number of these nodes must be identified and catalogued to form a national listing. This first listing should be large enough to establish the system, and to serve as a reference base for future listing. A listing of 10,000 to 30,000 nodes is suggested as a reasonable number to accomplish this requirement.

Once this list has been completed, it can be used immediately. However, if the motorist is to use the listing and associated instrumentation to find his way around the country, the basic listing should be simplified.

Record-keeping procedures, or route-following techniques, will require naming all nodes; otherwise the system would not be complete. However, the published listing distributed to motorists can be simplified by listing as destinations only those nodes which may be of value. For example, a motorist cannot stop at most nodes on the Interstate; therefore, these need not be listed as destinations. In fact, any location where parking or unloading space is not available can hardly be considered a reasonable destination.

Therefore, a file can be made containing only those nodes which may be desired as destinations on one axis of the matrix. Of course, all nodes are essential on the other axis. These listings may be furnished to the motorist for manual instrumentation, or used by machines which automatically describe an optimum route to any selected destination.

The simplification of the matrix is not essential to the instrumentation of route following; however, the time required for solution to the matrix increases as the square of the number of entries. The elimination of nodes which may not be used as destinations will substantially reduce the size of the matrix.

The other axis of the matrix may not be reduced because "present position" can be anywhere. It should be possible, however, to make up listings designed for particular areas which contain a very limited number of nodes. The area in question could be listed in detail with distant destinations limited to identifying nodes for entire areas.

Reduction of matrix size is important to the operation of the system. A more easily used list can be made available for manual operation, and the computation time required to solve the matrix for selection of the best route is reduced. The solution of a complete matrix may require months or even years, so any technique which reduces the required computation is important. The authors have confidence in the ingenuity of the industry to make even more significant reductions in the matrix solution. Undoubtedly, future computer developments will provide even faster solution times.

The establishment of a complete destination, node and branch file is essential to the overall development of a working system. The destination file should be accomplished concurrently with the naming and cataloguing of nodes and branches. This will prevent the publication of unrealistic designators and simplify the listings required by the public. The improvement in acceptance and learning time will be worth the effort. In addition, it should save a great amount of printing.

BRANCH DESIGNATORS

Today, branches or roads emanating from a point are designated by giving the direction of travel and the route number, such as north on I-95, or west on I-80, etc. Although this is an efficient system, it results in multi-digit numbers and leaves a lot to be

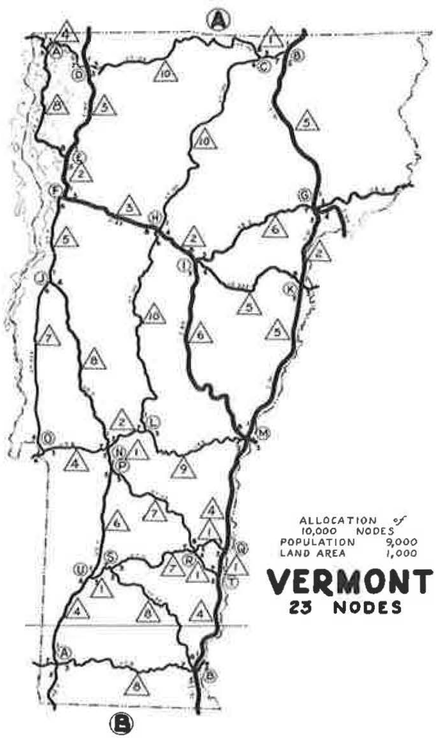

Figure 6. Nodal points formed by roads in Vermont.

desired if the delivery of this information to the driver is to be accomplished within a short time interval. Therefore, "branch designators" were developed to eliminate the transmission of multi-digit numbers.

Numbers 1 through 8, corresponding to points on a compass, were chosen as branch designators; for example, number 1 would be north, 2 would be northeast, and 3 would be east. It must be noted that the numbers 1 through 8 restrict the possibility of designating more than eight branches emanating from a node. If there should be more than eight branches emanating from a point, additional node numbers can be assigned to allow the designation of additional branches. A branch can have two designators assigned to it, one from each node terminating the branch.

There are several advantages in using the branch designator. It uses a minimum time-bandwidth product, because the designator can be expressed as a three-bit binary number. Therefore, it takes less time to get the information to the driver. This is especially important when the driver is traveling at high speeds and has to make rapid decisions. The ability to use three-bit binary numbers for expression also reduces language complexity. It can also designate the position of a vehicle on the road, by simply detecting the vehicle and referring to the distance from its node. For example, in Figure 6, if there was a detector located 5 miles from node A on branch 6, that point in the road would be designated as A6-5. If a vehicle is detected at that point you have its exact position.

Values can be assigned to the branches by some criteria such as time of travel, beautification, distance, or minimum stops. Thus, once a value has been put on the branches, one can select the optimum route based on personal preference.

Figure 6 shows Vermont with selected Interstate, U. S., and State roads forming 23 nodal points. The 23 nodal points are arbitrarily named A, B, C, D, etc. Branch designators are assigned to the branches in a systematic order corresponding to the point on a compass.

Values are computed for the branches in the following manner:

1. Assign factors to the Interstate, State, and U. S. routes; e.g., Interstate = 0.6, U. S. = 0.8, and State = 1.0.

2. Select a value for the longest branch, e.g., a value of 10, and give the rest of the branches values in proportions of their length to the length of the longest branch.

3. Multiply the values assigned to the various lengths of the branches by the factor assigned to the corresponding route. For example, the value computed for branch K5:

$$\left.\begin{array}{l} \text{Interstate route} = 0.6 \\ \text{Longest branch} = 10 \\ \text{Measured value} = 8 \\ \text{Computed value} = 5 \end{array}\right\} \ {}^{8}\!/_{10} \times 10 \times 0.6 = 5$$

After the nodes were selected, the designators appointed and the branch values assigned, a matrix was computed. The matrix (Fig. 7) describes the best route that can be followed from one node to any other node. For example, if one wants to go from

DESTINATION

PRESENT POSITION	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU	BA	BB
AA		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
AB	7		7	7	7	7	5	7	5	7	5	7	5	7	7	7	5	5	5	5	5	5	5
AC	8	3		8	8	6	3	6	6	6	3	6	6	6	6	6	3	3	3	3	3	3	3
AD	7	3	3		5	5	3	5	5	5	5	5	5	5	5	5	5	5	5	3	5	5	3
AE	1	1	1	1		5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
AF	1	3	3	1	1		3	3	3	6	3	3	3	6	6	6	3	3	6	3	6	6	3
AG	1	1	1	1	7	7		7	7	7	5	5	5	5	5	5	5	5	5	5	5	5	5
AH	8	1	1	8	8	8	4		4	8	4	6	4	6	8	6	4	4	6	4	6	6	4
AI	8	3	8	8	8	8	3	8		8	4	8	5	8	8	8	5	5	5	5	5	5	5
AJ	1	1	1	1	1	1	1	1	1		1	4	4	4	6	4	4	4	4	4	4	4	4
AK	8	1	1	8	8	8	1	8	8	8		8	5	5	5	5	5	5	5	5	5	5	5
AL	1	1	1	1	1	1	1	3	1	7	3		3	7	7	7	7	7	7	7	7	7	7
AM	8	1	1	8	8	8	1	8	8	8	1	7		7	7	7	5	5	5	5	5	5	5
AN	1	2	2	1	1	1	2	2	2	1	2	2	2		7	5	5	5	5	5	5	5	5
AO	8	3	3	8	8	8	3	3	3	8	3	3	3	3		3	3	3	3	3	3	3	3
AP	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		3	3	5	3	5	5	3
AQ	1	1	1	1	1	1	1	1	1	1	1	7	1	7	7	7		7	7	5	7	5	5
AR	2	2	2	2	2	2	2	2	2	8	2	8	2	8	8	8	2		7	4	7	7	4
AS	7	3	3	7	7	7	3	7	3	7	3	7	3	7	7	7	3	3		3	7	7	5
AT	1	1	1	1	1	1	1	1	1	7	1	7	1	7	7	7	1	7	7		7	5	5
AU	1	3	3	1	1	1	3	1	3	1	3	1	3	1	1	1	3	3	3	3		6	6
BA	3	3	3	1	1	1	3	1	3	1	3	1	3	1	1	1	3	1	1	3	1		3
BB	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8	1	8	7	

Figure 7. Matrix of branch designators for nodal points in Figure 6.

node AA (present position) to node AK, select the destination AK on the matrix taking the present position point, which would be AA at the start. The direction to travel is given by the branch designator at AA—AK. The next branch designator is given at AD—AK, and so forth until the driver gets to his destination, which is node AK. Thus the shortest route from node AA to AK at node AA is designated by the branch designator 3, at AD and AE by branch designator 5, at AF by 3, AH and AI by 4, and the next node would be AK, the destination.

If, however, the wrong branch is taken at any node, the driver would then proceed to the next node, and from that node he would get directions to the selected destination; therefore, one cannot be lost by following the matrix. It can be seen that the branch designator offers a systematic method for appointing a route, and that this method lends itself to a machine system. This system of designating routes can be used to provide directional information rapidly upon demand.

SUMMARY

In summary, no one should expect to find the answer to his problems. The mere possibility of such a system should raise many additional problems. The desirability of routes has not been defined, nor has a magic method for traffic control or assignment been uncovered. These problems are still with us. Future systems for route following must be based on the concepts developed through other research efforts. Meanwhile, the existence of a destination-selective communications system will be an aid toward these solutions.

This coding system may be used as a simplified method for describing location, vehicle position, complex routes, and a variety of other things. Further, it will be useful for greater machine adaptability. Describing this technique once more:

1. It is a nodal type description of the highway network; i.e., each intersection is defined by a unique code name.
2. A branch connects two nodes and is specified by one of eight numbers.
3. Branch designators are assigned using a compass direction criterion.
4. Node names should be assigned by a system which allows the name to contain a maximum amount of information, i.e., state, route number, location, etc.

The branch designator is used exclusively to define the route one may elect to follow. Because this designator is only one of eight numbers, it requires a minimum time-bandwidth product for transmission.

Those who have worked with this technique believe it should be developed and used whenever machine-language description of a location or vehicle position is required, and that it should be used as the address format for all highway communications.

ACKNOWLEDGMENT

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