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FINAL REPORT

REFINEMENT OF A METHODOLOGY FOR SITING MAINTENANCE AREA HEADQUARTERS

by

David C. Wyant
Research Engineer

(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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ABSTRACT

Prior to this study, a methodology that generates travel time, or isochronal, contours around area headquarters or the housing bases of maintenance crews was developed. The methodology was then pilot tested for the Charlottesville Residency, and was deemed to be a viable aid for use in making decisions on locations for area and subarea headquarters. However, refinement of the methodology to make it a practical and implementable procedure for use by the Virginia Department of Highways and Transportation was needed. The present study was undertaken for that purpose.

The conclusions from this study are based solely on maximum travel times; no consideration was given other maintenance concerns such as future growth in the area, the number of maintenance workers or supervisors, maintenance equipment, miles of roadway, or areas of right-of-way. The resultant methodology is intended for use only as an aid in decisions concerning the location of area headquarters and subarea facilities.

Implementation of the methodology statewide suggested that area headquarters be located at 43 of the 45 residencies (an increase of 22), that a subarea facility be located at one residency, and that a headquarters be removed from another residency. In addition, 1 new area headquarters and 5 new subarea facilities are needed in new locations. In other suggestions of the researcher, the number of area headquarters should be decreased from 236 to 119 and the subarea facilities from 29 to 25. After determining the future growth in each residency and its impact on the location of area headquarters and subarea facilities, the optimum number of maintenance facilities can be defined. The number of area headquarters and subarea facilities should be between the present number and the number suggested by the researcher.

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PREVIOUS WORK

In 1984 the Maintenance Division of the Virginia Department of Highways and Transportation and the Joint Legislative Audit and Review Commission, the latter of which had been studying facets of the Department's maintenance operations since 1981, requested an evaluation of the need for the number of area headquarters in operation at that time and of the suitability of their locations. As part of this evaluation, it was necessary to develop a methodology for determining how area headquarters should be sited to best enable the Department to meet its maintenance responsibilities. This task was undertaken in May 1984.(1)

In summary, that effort led to the conclusion that the work indicator most affecting the optimal location of an area headquarters is the travel time from the headquarters to the work sites. Using this indicator, a computer model was developed and pilot tested in the Charlottesville Residency (Albemarle and Greene counties). The methodology generates travel time (isochronal) contours around any number of area headquarters within a geographic area, and thereby allows the contours for several headquarters to be examined for overlap and for any areas that can not be reached within the established travel time to be identified. Consequently, the need for headquarters or subarea facilities to be added or eliminated, or for headquarters to be reduced to subarea status, can be established.(2)

The methodology developed was deemed by Department personnel and the author to be a viable aid for use in making decisions on the location of area and subarea headquarters. However, several questions needed to be answered to make the methodology a practical and implementable procedure; thus, a second study was needed.

OBJECTIVE AND SCOPE

The objective of this second study was to refine the methodology into a practical and implementable procedure for use by the Department of Highways and Transportation.(3) More specifically, the following questions were considered in this study.

1. What is a reasonable maximum travel time for a headquarters crew?

2. How sensitive is the methodology to variations in the number of intersections?

3. How sensitive is the methodology to the travel speeds for the various classes of roads?

4. What is the average travel speed for each class of road?

5. Can the classes of roads used in the earlier study be equated to the Department's present road classification or traffic group system?

6. What is the break-even cost of closing a headquarters as compared to increasing the travel time or establishing a headquarters and reducing the travel time?

It was proposed that in addition to seeking answers to these questions, the study validate the methodology in the Coastal, Piedmont, and Valley and Ridge geologic provinces, using a typical county in each. Near the completion of the second study in midsummer of 1985, the Maintenance Division asked the researcher to perform analyses of all the residencies in the state as well as one toll road and one bridge-tunnel operation. Since the researcher was concentrating most of his efforts on this study (80%), the tasks in the original working plan were being completed significantly sooner than estimated and for substantially less money. So, it was decided that the additional work requested could be completed within the estimated budget presented in the working plan, but that the deadline for the final report on the study would need to be extended several months.

RESULTS

Maximum Travel Time for Headquarters Crew

In the earlier study,(2) roads were classified into the eight categories shown in Table 1 on the bases of road type (interstate, primary, or secondary), alignment (straight, winding, hilly, or flat), and traffic control (frequent, some, or little). Since the classes of roads reflect factors that affect the average speed of traffic, which is directly related to travel time, the geographic location of the road should not influence the maximum time allotted for travel from an area headquarters to a work site. In other words, the maximum travel time should be the same in all areas of the state. The major criterion in establishing a maximum travel time is the maximum nonproductive time the Department is willing to accept. Therefore, a decision was needed from management.

Table 1

Classes of Roads Used in Methodology

Class	Description
1	Any interstate road
2	Any rural primary road or any primary road with little traffic control
3	A suburban primary road, a primary road with some traffic control, or a primary road with many horizontal or vertical curves
4	An urban primary road, a primary road with frequent traffic controls, or a steep primary road
5	A paved, relatively flat, smooth, and straight secondary road
6	A paved secondary road with either horizontal or vertical curves, or a rough secondary road
7	An unpaved, relatively flat and straight secondary road
8	An unpaved secondary road with either horizontal or vertical curves

To obtain information for the guidance of Department management, a literature search and a survey of other organizations that require travel of their employees to work sites were conducted. Surprisingly, no useful data were found in the literature nor were any available from the organizations contacted.* However, as shown in Table 2, the literature did provide information on the nonproductive time attributal to fatigue, personal matters, and delays for persons employed in work activities similar to those performed by the Department's maintenance personnel. (4,5)

Table 2

Nonproductive Time

Cause	Percentage[1]	Percentage[2]
Fatigue	8.0	5
Personal Matters	8.3	5
Delays	6.3	10
TOTAL	22.6	20

[1]From references 4 and 5.
[2]From reference 6.

As can be seen in Table 2, the total nonproductive time is between 20.0 and 22.6 percent, or 1.6 and 1.8 hours in an 8-hour day. For an 8-hour day, this would leave from 6.2 to 6.4 hours each day for travel and productive work at the job site.

Using this limited information and the Department's experience in maintenance operations, management decided that 30 minutes should be the maximum time allotted for travel from any headquarters facility to a work site. It should be emphasized that 30 minutes is the maximum time allotted, and that a large number of work sites would be reached in less time. Based on the data in Table 2 and the maximum 30-minute allotment for travel, a crew working the entire day at one location would put in from 5.2 to 5.4 hours of productive time. Management was willing to accept this worst case situation, since the majority of the work performed by most headquarters would not be at this outer limit. Of course, as the work sites become closer to the headquarters, the time for productive work lengthens by double the reduction in the one-way travel time.

*The author was also surprised to learn from power and telephone companies that they had no maximum travel time; they send their personnel wherever they are needed.

Sensitivity Analyses

The methodology developed in the earlier study was deemed to be a viable, worthwhile tool, but the effects of two variables inputted into the computer program -- namely, number of intersections and travel speed for the class of road -- were unknown. To ascertain the sensitivity of the methodology to changes in these variables, a pilot study was conducted in the Charlottesville Residency, a typical residency and one for which data were available from the earlier study.

Intersections

In the earlier study, all intersections in the Charlottesville Residency (Albemarle and Greene counties) had been logged. With this information, the route requiring the least travel time from any headquarters to any intersection could be determined, but some calculations would require considerable computer time. Of course, as the number of intersections increases, the number of possible routes increases, the number of required iterations increases exponentially, and the computations become increasingly expensive.

So, for the current study only the main roads used primarily by state maintenance personnel to get to work sites from area headquarters were inputted into the computer model, rather than all the roads in the highway system. In most cases, minor intersections between major intersections were ignored and the segments of road were treated as one long segment.

Table 3 gives the numbers of intersections used in the early and present computer models to determine the farthest work site from a maintenance area headquarters in the Charlottesville Residency that could be reached by a crew in the maximum allotted travel time of 30 minutes.

Table 3

Number of Intersections Used in Generating 30-Minute Contours

Area Headquarters	Model Early	Model Present
Batesville	155	45
Boyd Tavern	187	57
Free Union	118	51
Greene	150	43
Keene	110	39
Yancey Mills	213	46

As shown in Table 3, the number of intersections within a 30-minute isochronal contour was reduced better than half in all cases, and in most cases (for 4 out of 6 area headquarters) better than two-thirds. The total number of intersections inputted into the model for the Charlottesville Residency was reduced to approximately a third of those used in the earlier study (259 from 770). Because there are overlaps of the isochronal contours for the headquarters shown in Table 3, the total number of intersections in the table exceeds the number inputted into the model.

Although this reduction in computer time and expense is significant when considering the large number of residencies (45) to be examined, the effect of the reduction in intersections inputted upon the accuracy of the isochronal contours is more important. For the six area headquarters noted in Table 3, the 30-minute isochronal contours were essentially identical. For several of the headquarters, one or two intersections were excluded from the 30-minute contours while for several other headquarters additional intersections were picked up when the model with the reduced number of intersections was used.

In summary, the reduction in the number of intersections inputted into the computer model had an insignificant effect upon the isochronal contours, but provided a significant savings in labor and computing costs.

Travel Speed

As indicated earlier, roads were classified into eight categories according to the road type, traffic control conditions, topography, road alignment, and the riding surface. For each class of road, an average speed of travel in a dump truck, which is the primary mode of travel of the Department's field forces, was established. In the earlier study in which the Charlottesville Residency was used to test the methodology, the average speeds were established from a survey of Charlottesville Residency personnel (Table 4). To test the sensitivity of the methodology to changes in the travel speed, each speed shown in Table 4 was reduced by 5 mph and inputted into the methodology to produce isochronal contours for the Charlottesville Residency. This procedure was repeated for increases in the travel speeds of 5 and 10 mph. Table 5 indicates a significant change in the number of intersections for each headquarters for each 5 mph change in speed. When isochronal contours for the various speeds are drawn on a map, there are significant changes in the area covered in the 30-minute travel time for all area headquarters.

Table 4

Average Travel Speeds Provided by Charlottesville Residency

Class of Road	Average Travel Speed (mph)
1	45
2	40
3	30
4	25
5	35
6	20
7	30
8	20

The results shown in Table 5 should be typical of those for other parts of the state because of the variety of population densities and types of terrain and roads in the Charlottesville Residency. Some of the headquarters are located in rural areas with no interstate highways, while others are in more urban areas with interstate, primary, and secondary roads. Some headquarters are located where population growth and development characterize the entire area, while others are located in lightly populated areas where there are infrequent intersections but where the distribution of the work load requires crews to travel into outlying areas with a dense population and numerous intersections.

Table 5

Number of Intersections for Variations in Travel Speeds

Residency or Area Headquarters	Travel Speed (mph) -5	Table 4 (Avg.)	+5	+10
Batesville	29	45	64	80
Boyd Tavern	40	57	70	88
Free Union	23	51	71	94
Greene	30	37	55	69
Keene	27	39	56	78
Yancey Mill	28	46	62	80
Residency	64	80	102	131

In conclusion, the average travel speed for each class of road is very critical to the shape of the isochronal contours. Therefore, accurate travel speeds will be needed if the methodology is to produce accurate results.

Average Travel Speed

Although the average travel speeds between intersections for the different classes of roads established from a survey of the Charlottesville Residency personnel appeared to be valid to the researcher, it was decided that the speeds at which maintenance forces travel on the eight classes of roads should be monitored in different areas of the state. For this activity, the following guidelines and limitations were observed.

1. Crews were monitored in area headquarters facilities in all three geologic provinces (4 districts, 11 area headquarters, and 12 counties).

2. No one was notified of the monitoring so that the maintenance personnel would not deviate from their normal driving habits.

3. Only dump trucks going to work sites in the morning, generally departing between 8:00 and 8:30 a.m., were monitored for travel speed.

4. For each truck, the actual travel speed was recorded. In addition the class of road, the distance between intersections, and the time of travel between intersections were recorded for calculations of the average travel speed between intersections and verification of the travel speed recorded.

After the monitoring of the crews from the 11 area headquarters, it was concluded that the travel speeds for the eight classes of roads shown in Table 4 should be taken as the average speeds. For all of the classes of roads there were cases where some crews drove faster and some drove slower. For each class the deviation of speed from the average never exceeded 5 mph. Also it should be noted that for all classes the speed was generally from 5 to 10 mph slower than the posted speed limit. Since the monitoring methods were not very precise (± 3 mph at the most) and the contour plotting produced errors of several miles, it was decided that the speed should not be established to an accuracy of 1 mph but to 5 mph. Also, it was decided that the travel speed between intersections should be the average of the monitored speeds and not the maximum, minimum, or 75th or 85th percentile speed.

Classes of Roads

Different road classification systems (functional, traffic count, and administrative) were studied to ascertain the feasibility of using one of these rather than the system proposed in the earlier study (Table 1). Of the systems examined, the administrative system was most similar to the one earlier proposed, since it classifies according to type of road (interstate, primary, secondary, or urban). However, it does not consider other factors, such as alignment, topography, riding surface, and traffic conditions, that have a direct bearing on travel speed. Consequently, it was decided that the proposed system should be kept since it is simple and straightforward and no other presently used system would adequately replace it. However, this decision was not considered to be critical since the methodology will not be used frequently by the Department. Following the initial use (see Implementation Section), the methodology probably will be used only every five to ten years to determine if changes in the location of area headquarters or their boundaries are necessary. In most cases the methodology will be used where travel speeds are changed because roads are upgraded and traffic controls are installed.

Cost Analysis

Where travel time contours for neighboring maintenance facilities overlap a large area, (Figure 1), thus indicating that an area headquarters or subarea facility should be eliminated, then no cost analysis is necessary because money will be saved by closing the facility in the overlapped area. For example, in Figure 1, where the isochronal contours for headquarters #1 and #2 completely cover the contour of headquarters #3, money can be saved by closing headquarters #3.

If overlaps are significant but do not cover all the area within a headquarters as illustrated in Figure 2 for headquarters #4, then a cost analysis would indicate what savings, if any, could be realized by eliminating headquarters #4 and increasing the travel times for headquarters #5 and #6 beyond 30 minutes. The cost of maintaining a headquarters over an extended period of time, generally 20 years, should be compared to the costs of additional travel plus additional nonproductive time.

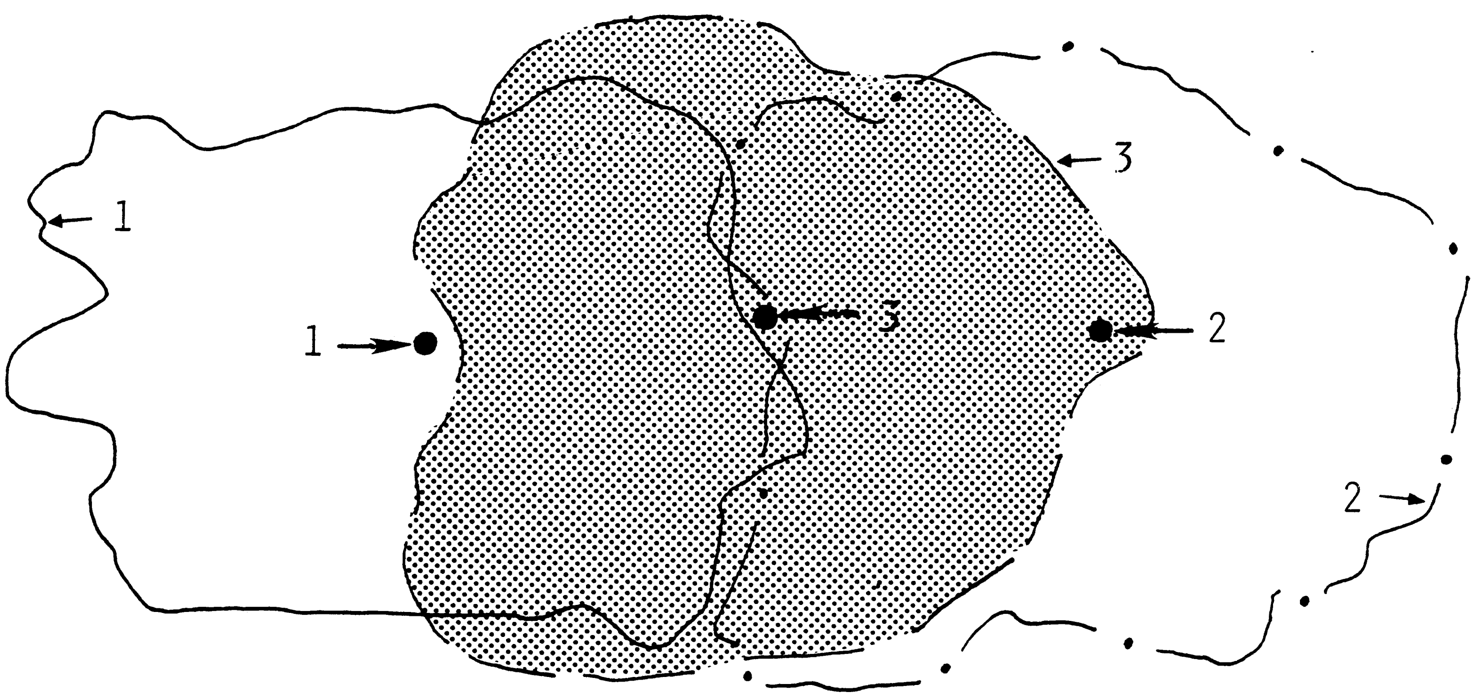

Figure 1. Contours for 3 headquarters. Location #3 not needed. Solid line is contour for headquarters #1 and dash line for headquarters #2. Shaded area is encompassed by headquarters #3 contour.

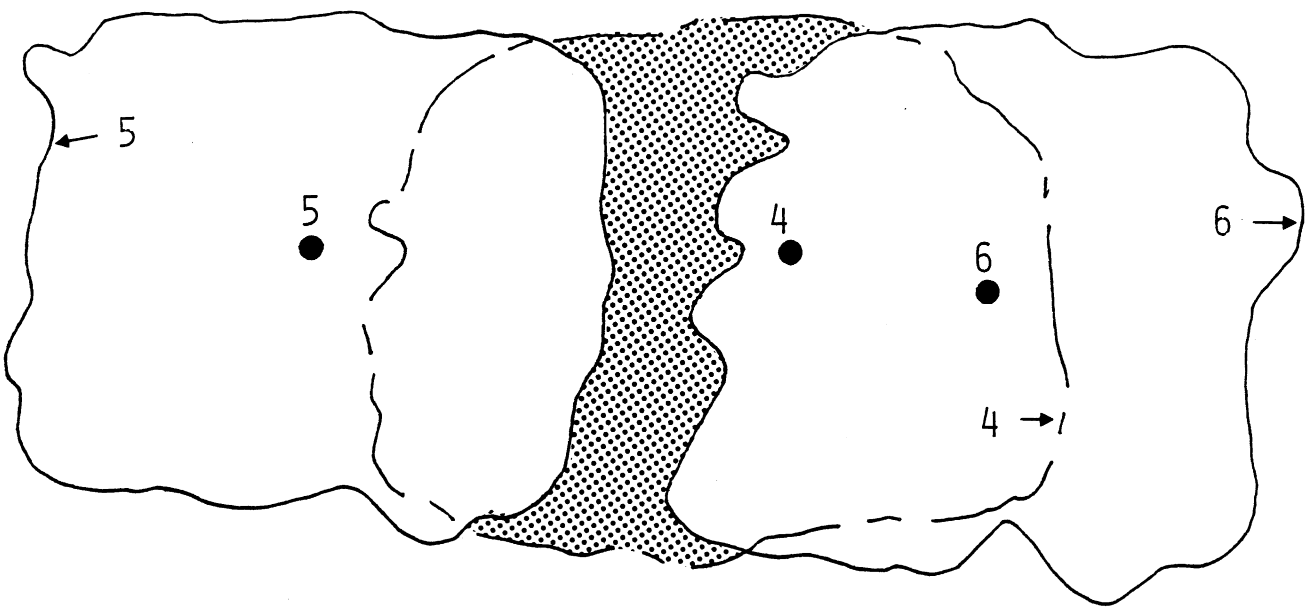

Figure 2. Shaded area cannot be reached within 30 minutes from headquarters #5 or #6.

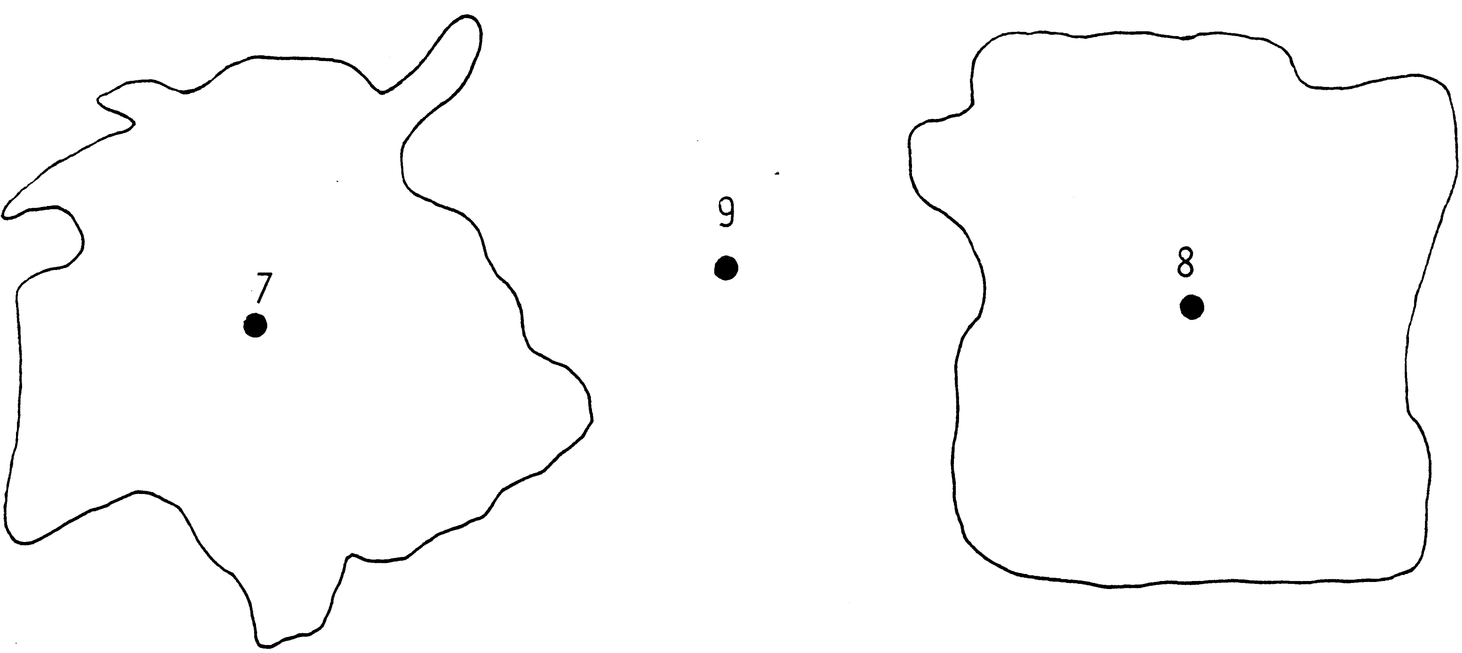

Figure 3. Location #9 is needed in the uncovered area.

When large areas cannot be reached within the allotted 30-minute travel time (Figure 3), the difference between savings in reduced travel and increased productive time from establishing location #9 and the cost of the increasing travel time for locations #7 and #8 should be compared to the cost of constructing and maintaining a new facility in the uncovered area. It may be more economical over a 20-year period to transport crews from locations #7 and #8.

In summary, if a headquarters or subarea facility is located in an area where isochronal contours of neighboring headquarters partially overlap or are close to overlapping, then a cost analysis is necessary to determine if that facility can be economically justified. Conversely, if large areas cannot be reached in 30 minutes from existing headquarters locations, then a cost analysis is required to justify establishing a new facility.

From this discussion one can see that each case is site-specific and involves different factors, such as travel time and mileage, number of employees used for each maintenance activity, and the number and type of vehicles for each activity.

IMPLEMENTATION

Near completion of the validation effort in the three residencies, the Maintenance Division asked the researcher to perform analyses of all the residencies in the state, as well as one for a toll road and a bridge-tunnel operation. The Research Council administration agreed to the request, and decided the work could be done under the allocation for the validation study, but that an extension of the deadline for the final report was needed.

Comments on the validation effort are made below and the results for the three residencies -- Lebanon, Chesterfield, and Norfolk -- are then summarized with those of the remaining residencies.

1. The validation produced results similar to those obtained in the earlier study of the Charlottesville Residency.

2. From the contours generated, physical barriers such as mountains and rivers were more evident than at first glance. In other words, it could be seen that an intersection on the opposite side of a physical barrier, and that appeared close to another intersection on the two-dimensional map, might not be included within the 30-minute contour. The routes through mountains and over rivers were defined and limited the area covered on a map.

3. The shortest route in time to an intersection from a headquarters was delineated. Two adjacent intersections at a distance from a headquarters could be reached by two different routes.

For statewide implementation of the methodology, data were needed on the roads in each residency. Therefore, an example of the Charlottesville Residency data, blank data forms, a table of the classes of roads (Table 1), and instructions (see Appendix) were provided to the Maintenance Division for distribution to the 45 residencies in August 1985. By October 1985, all the data from the residencies were collected for processing. The forms were checked for correctness and processed by Research Council computer personnel. The computer output was then used to draw, on county maps, isochronal contours for all highway facilities where maintenance crews are based (residency, headquarters, subarea locations, toll facilities headquarters, and correctional units). Sometimes, overlooked errors in the data necessitated extra runs, and in several cases the original and extra runs were delayed because additional information and verification of the data were needed from the residency. The contours for the residencies, were forwarded to the Maintenance Division with the researcher's suggestions for changes.

It is emphasized that this methodology is a guide to assist management in decisions on the location of a highway facility and that other factors, such as future growth and development, need to be considered before the final decision is made. Since the contours generated for the Charlottesville Residency in the earlier study are available in the report on that work, only a summary of the suggestions made by the researcher to the Maintenance Division are presented here. Table 6 summarizes the researcher's suggestions by district. Although it is suggested that some facilities remain as they are, the boundaries of their work areas may need to be changed to reflect the 30-minute travel time.

Table 6

Suggested Changes By District

District	Suggestions
Bristol	1. Keep 23 of the present headquarters. 2. Keep 1 of the present subarea facilities. 3. Add 1 headquarters and 1 subarea location. 4. Change 2 headquarters to subarea locations. 5. Close 11 headquarters.
Salem	1. Keep 18 headquarters and 1 subarea location. 2. Add 1 subarea location. 3. Change 1 headquarters to a subarea location. 4. Close 10 headquarters.
Lynchburg	1. Keep 9 headquarters. 2. Change 8 headquarters to subarea locations. 3. Close 10 headquarters.
Richmond	1. Keep 18 headquarters. 2. Close 14 headquarters and 5 subarea locations.
Suffolk	1. Keep 8 headquarters and 1 subarea location. 2. Change 2 headquarters to subarea locations. 3. Change 1 headquarters at a residency to a subarea location. 4. Close 7 headquarters and 1 subarea location.
Fredericksburg	1. Keep 12 headquarters. 2. Add 1 subarea location. 3. Change 1 headquarters to a subarea location. 4. Close 14 headquarters.
Culpeper	1. Keep 12 headquarters. 2. Change 1 headquarters to a subarea location. 3. Close 6 headquarters.
Staunton	1. Keep 14 headquarters 2. Add 2 subarea locations. 3. Change 1 headquarters to a subarea location. 4. Close 12 headquarters and 1 subarea location.
Northern Va.	1. Keep 4 headquarters. 2. Change 1 headquarters to a subarea location. 3. Close 9 headquarters and 1 subarea location.

CONCLUSIONS

There are presently 45 residencies, 236 area headquarters, and 29 subarea facilities. Area headquarters are located at 21 of the 45 residencies, and the application of this locational methodology indicates that area headquarters need to be located at 23 other residencies. One of the existing 21 headquarters at a residency is poorly sited and should be closed. In addition, 1 residency should have a subarea facility located at its site.

Besides changes at the 45 residency locations, 1 area headquarters and 5 subarea headquarters are needed in new locations. Seventeen of the existing 236 headquarters should be changed to subarea status, and 93 headquarters should be closed. Of the 29 subarea facilities, 8 should be closed. The number of area headquarters should be reduced from 236 to 119, and the number of subarea facilities from 29 to 25.

It is emphasized that the closing of a facility is suggested only on the basis of an established travel time, with no other factors being considered. This methodology is only a guide to aid in the final decision concerning the location of area headquarters or subarea facilities and has no bearing on other maintenance concerns such as the numbers of maintenance workers or supervisors, maintenance equipment, miles of roadway, or acres of right-of-way. However, if made, the suggested changes would change the reporting headquarters of some personnel and the housing location of some equipment.

Since only present conditions and not future growth, which is occurring in most areas of the state, were considered in this study, the number of maintenance facilities suggested by the researcher should be the minimum number needed by the Department. When future growth, which is the primary remaining factor in the decisions on the locations of maintenance facilities, in a residency is considered, the optimum number of facilities will be between the researcher's suggested number and the present number.

RECOMMENDATION

Since this study considered only existing conditions and did not project into the future, the following recommendation is made to the Department.

The future growth in each residency and its impact upon the traffic movement should be projected by residency and district personnel. With these growth projections and changes in traffic conditions, the projected isochronal contours for maintenance facilities in the area can be determined. By comparing these contours with the ones generated in this study, decisions on headquarter locations can be made to meet the Department's present and future maintenance housing needs.

ACKNOWLEDGEMENTS

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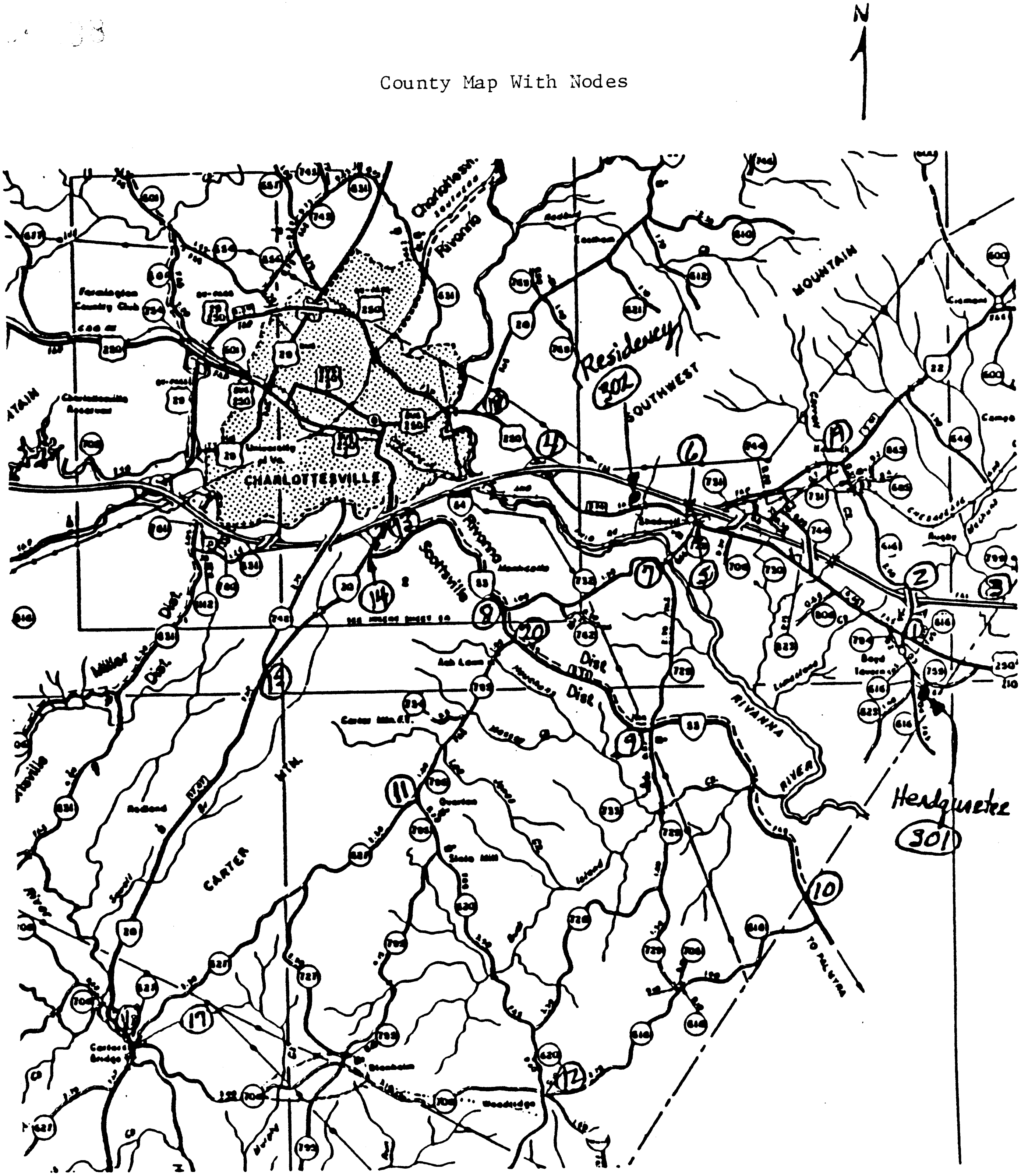
APPENDIX

Example of Materials Presented to Maintenance Division for Collection of Data in Statewide Implementation

County Map With Nodes



Example of Data Form
Albemarle County - Charlottesville Residency

1st Node	2nd Node	Distance Between Nodes, mi	Class of Road Between Nodes
301	1	0.5	6
1	2	0.4	6
1	5	3.5	2
2	3	1.21	1
2	4	5.52	1
2	19	2.55	6
4	18	1.76	2
4	13	2.64	1
4	302	1.18	2
5	6	0.28	2
5	7	0.65	6
6	19	2.50	3
6	302	0.82	2
7	8	1.90	6
7	9	2.70	6
8	20	0.30	3
8	14	2.89	4
9	10	3.84	3
9	20	2.63	3
11	20	2.65	6
11	12	5.10	6
11	17	5.70	8

Classes of Roads Used in Methodology

Class	Description
1	Any interstate road
2	Any rural primary road or any primary road with little traffic control
3	A suburban primary road, a primary road with some traffic control, or a primary road with many horizontal or vertical curves
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