Cletus R. Mercier

A Sufficiency Rating System for Secondary Roads in Iowa

Volume I

June 1985

Iowa DOT Project HR-264
ERI Project 1654
ISU-ERI-Ames-86004

Iowa Department of Transportation

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report

College of Engineering
Iowa State University

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Submitted to the Highway Division,
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ENGINEERING RESEARCH INSTITUTE
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EXECUTIVE SUMMARY

County engineers in Iowa face the dual problems of rapidly escalating costs and a decreasing rate of growth of revenues. Various priority systems are in use, ranking projects for inclusion in road improvement programs, but they generally have weaknesses when used to compare one project with another in a different location.

The sufficiency rating system has proven to be a useful tool in developing a priority list of projects for primary road systems, but there are none currently in use for secondary road systems. Some elements of an existing system used for primary roads could be modified for use with secondary roads, but would require extensive changes.

The research reported here, sponsored by the Iowa Department of Transportation, was undertaken to develop a sufficiency rating system which could be used for secondary roads in Iowa and to produce the necessary forms and instructions to aid county engineering personnel in their efforts to complete the ratings for roads within their county. If a usable system were available that would yield reasonable results, county engineers would have an additional tool available to assist them in arriving at a defensible road improvement program.

A complete literature search was done, in order to better understand the form and function of the sufficiency rating systems that have been used. Information gathered in this search was used to develop a questionnaire, which was mailed to all county engineers in the state, plus selected engineers from the Iowa Department of Transportation.

The questionnaire included a comprehensive list of commonly used rating criteria, organized by rating category. Respondents were asked to rank the criteria in order of importance (as they perceived them) and also to weight the criteria. Responses were analyzed to determine which of the criteria were judged to be most important and to suggest relative weights for each.

The result is a rating system described in Volume 2 of this report. It utilizes fourteen (14) rating criteria, organized into the three categories of:

1. Condition and Maintenance Experience,
2. Safety, and
3. Service.

Relative weights were determined from the responses and applied to each of the criteria.

The Empirical Model chapter describes the system in further detail, including an explanation of the proposed scaling factors. Data collection and evaluation forms were also developed. A copy of each is included in Appendix C, along with a guide to their completion.

A brief trial run was completed, using the proposed system and the forms. The purpose of the trial run was to test the use of the forms and the instructions. A few changes were made as a result of the trial run.

A second, more complete test of the proposed system was made in another county. A sample was drawn of about 20% of the total mileage of the county (of trunk, trunk collector, and area service roads - each sampled separately). Complete sufficiency ratings were accomplished for each of the road segments in the sample. Additional changes were suggested by the results of the more complete test. These changes plus changes suggested by the Office of Advance Planning and Research Division Staff of the Iowa DOT have been incorporated into the model and system described in this report.

The report is presented in two volumes. Volume 1 is an overview of the methodology of sufficiency rating systems and a brief description of the questions to be addressed by the study. Volume 2 describes the model and how it was developed. It also includes the report appendices.

ACKNOWLEDGEMENTS

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Each County Engineer in Iowa assisted in this research by responding to a telephone inquiry and, in most cases, also completing and returning a questionnaire that provided the basis for the rating model suggested by this research. Their assistance and support is sincerely appreciated.

An Advisory Committee provided the necessary review and comments on the findings of the research. The following persons provided this essential service:

Delano S. Jesperson, Story County Engineer

Robert L. Gumbert, Tama County Engineer

Eldo W. Schornhorst, Shelby County Engineer

Gene R. Hardy, Dallas County Engineer

Lowell E. Richardson, Local Roads, Iowa Department of Transportation

Their assistance is greatly appreciated.

However, the opinions, findings, and conclusions expressed in this publication are those of the author and not necessarily those of the Highway Division of the Iowa Department of Transportation.

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Chapter I

INTRODUCTION

Managers of Iowa's secondary road network are facing the dual problems of rapidly escalating costs and a decreasing rate of growth of revenues. Various priority systems are used to rank projects for inclusion in road improvement programs, but they generally have weaknesses when used to compare a particular project with another in a different location, especially since all worthy projects cannot always be funded.

A useful tool for developing a priority list of projects is a numerical system for rating roads and structures. The Iowa Department of Transportation (DOT) uses such a system, called sufficiency ratings. All primary roads in Iowa have been analyzed using the sufficiency rating system developed by the Iowa DOT and are updated annually. The results are published each year (as provided by law) and used in conjunction with the development of the revised five year construction program.

The sufficiency rating system allows highway administrators to measure a particular road segment and its structures in relation to with all other road segments and associated structures in the state against a selected level of service.[1] The qualitative measures described by a given level-of-service relate mostly to the traffic volumes and operating speeds on a given road segment. The selected level-of-service will vary, according to the relative importance of the given road segment to the entire primary road network. The sufficiency rating represents an evaluation of how well a given road segment meets the necessary requisites for the selected level-of-service.

A sufficiency rating system would be a useful tool for managers of secondary road systems as well, in that it would provide a method for comparing projects throughout a jurisdiction. Since it is impossible to fund all needed projects, sufficiency ratings would provide a numerical system usable for ranking projects in a priority order. Like the sufficiency rating system used for primary roads, it could be used to evaluate the elements of safety, service provided, and condition.

There are additional advantages to the development of such a system:

1. Fewer and less severe accidents should occur on roads that are constructed and maintained in accordance with current design standards and traffic needs.
2. Benefits should be maximized from the expenditure of available funds.

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[1] The level of service selected is a qualitative measure as defined by the 1965 Highway Capacity Manual.

3. Priority decisions could be more easily defended.

These potential advantages could be somewhat difficult to substantiate, and would suggest some additional research topics. At this time, they must be termed as "philosophical" benefits that strongly support the use of a sufficiency rating system.

Some elements of an existing sufficiency rating system, such as that used by the Iowa DOT could be modified to be used for secondary roads, but three serious differences between primary roads and secondary roads preclude direct use without extensive modification. One is the significant difference in the traffic using the roads (primary and secondary), both in terms of traffic volume and in the character and composition of the traffic. The second is in the use of level-of-service as an appropriate measure for secondary roads. Level-of-service normally applies to high capacity, paved roads with significant amounts of traffic. Secondary road traffic volumes are generally low and, quite often, speeds are restricted by geometric design and/or road surface conditions, instead of traffic volume. Therefore, it would seem to be better to use some other qualitative measure for comparisons. The third is in the rating system itself. The Iowa DOT system considers gravel and low type bituminous surfaces to be inadequate as a surface for primary roads and, as such, provides either a very low rating or a zero rating for several criteria rated. Yet, gravel and low type bituminous roads are a significant part of the secondary road systems in Iowa.

There has been some work done in developing sufficiency rating systems for secondary roads. Some details of the results of that work is discussed in the Review of Literature. It is likely that some of the concepts used in the development of these systems could apply to an evaluation of Iowa's secondary roads. Certainly, the goals of the rating systems should be similar to the goals of any numerical evaluation system used for secondary roads.

Chapter II

REVIEW OF LITERATURE

2.1 ROAD RATINGS - PART OF THE PLANNING PROCESS

Road rating makes little sense unless it is placed in the proper perspective and sequence among all the component parts that lead to an approved annual program or so-called "capital budget". It then becomes of value as it helps translate highway needs into a constructive program.

However, prior to rating, it would be desirable to have already created a long-range program with a tentative schedule for completion of its various elements. This suggests that;

1. certain highways have been "justified',
2. they have been classified into systems, and
3. reasonable standards have been established in accordance with the economy.

It would also be helpful if decisions had already been made regarding needs, fiscal capability, and resource allocation.

The first concern of the planning process is to establish goals, considering needs and fiscal capabilities, followed by determination of the means used to reach those goals and the placement (order of achievement) to achieve the highest good. Once the long-range plan has been completed and fiscal arrangements made to assure planned rate of achievement, initial planning for translation of the plan into reality can begin by ranking the sections of highways for improvement. The objective of the initial planning - carry out the master plan in intent and time (Campbell, pp. 75-76).

However, road segments with the most critical deficiencies do not promise the greatest return on investment for the improvement. It also becomes apparent that failing to adhere to the results of the critical deficiency ratings can cause a deviation from stated objectives. The saving aspect is that there is usually a backlog of critically deficient projects, making it possible to select the emergency projects and then add the most economically efficient from the rest.

2.2 PURPOSE OF RATING

Rating systems are used for a variety of purposes. Management may use ratings for part or all of the following ends (Campbell, p. 79):

1. To alert to impending deficiency.
2. To provide warrant for action.
3. To signal shifts in need.
4. To complement road life studies.
5. To show system-wide status.
6. To provide comparative performance records.
7. To provide data for apportionments.

8. To assist comptroller and fiscal planner.
9. To assist in periodic review of needs.
10. To provide data for public information.
11. To enlighten pressure groups.

The first two criteria provide for the isolation of specific deficiencies, suggesting the appropriate remedy.

The list also shows how ratings point toward the ultimate formation of short term programs (of up to five years), but quite often it is for programming for the annual budget.

The critical part of programming is the ranking of needs. This is a requisite so that programming can proceed in a systematic, straightforward manner. It is also important;

1. to assure continuity of purpose and plan,
2. to reduce the need for crash and crisis programming, and
3. to hold the line against pressures when revenues are scarce.

For these reasons, a rating system is needed which is consistent, and which is reproducible -- a rating that would measure the adequacy of a given section of highway in terms of a norm or established standard.

For such a rating to be reproducible, either by the same or different evaluators, it should be a numerical rating with a convenient scale. The component parts to be scored should be (as far as possible) evaluated by a common set of standards.

2.3 PHILOSOPHY OF RATING

If the ratings are reproducible, it is possible to compare the needs of one rated segment of the highway network against another, in that the composite rating for each reveals its relative deficiency as compared to the established "ideal". Final decisions on programming can then be made, based on the combination of;

1. fiscal capability, and
2. conditions existing within sections of the highway network that are considered intolerable.

Note that these elements are not always totally compatible. It is likely that revenues will not match revenue needs -- that is, in a given annual program, some needs will not be filled.

What is needed is a measure of immediacy of needs so that ranking of projects can be made. Need and urgency are relative, and require some qualifying measure to show this. Adjectives can be used, such as vital, great, fair, or casual -- with respect to needs, or immediate, critical, serious, or moderate -- with respect to urgency. Unfortunately, interpretation of these adjectives can be difficult, so a numerical scale is needed to indicate urgency of need.

Psychologically, a number or formula gives the impression of accuracy. It should be realized, however, that there is no particular virtue in numbers or formulae as such. Improperly used, they can be even more misleading than adjectives. Although presentation is mathematical, much engineering knowledge is still descriptive. Information expressed by numbers or formulae is merely an indication of the level of scientific organization of experience. Therefore, numerical data still have no absolute significance. They are useful only insofar as they are suitable to delimit certain classes of phenomena.

Adequacy ratings measured on a reasonably wide scale (usually zero to 100 percent) provide a graduated numerical scoring. The resultant score provides the means for comparison of critically deficient sections,[2] indicating degree of urgency. A rating of 100 indicates that the given road segment completely meets desirable standards. By the same token, a road segment given a rating of 60 is in greater need of improvement than one with a rating of 75.

Relative urgency can be indicated in needs studies by setting up a dividing line between "tolerable" and "intolerable", the "intolerable" sections forming a current backlog of needs. With the passage of time, some of the "tolerable" sections would eventually become "intolerable" and form the basis for future programming.

However, should the backlog of needed projects exceed the current fiscal capability, they may have to be spread through several years. Therefore, individual projects need

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[2] The score can also be used to define the cut-off or demarcation between what is considered critical and non-critical.

to be rated for priority on a year-to-year basis. This requires a still finer scale of values be drawn within the intolerable range and within the tolerable range -- as the more critical needs are filled.

Such a system has been developed. A numerical rating system, called a "sufficiency rating system" was developed by the Arizona Highway Department in 1946. It attracted immediate attention, especially from other states as they faced the post World War II problem of deciding which highway needs should be filled first (Willey, p. 3). Currently, nearly every state uses some form of adequacy (or sufficiency) ratings as a systematic procedure for periodic evaluation of highways for improvement programming (Zegeer and Rizenbergs, p. 15).

2.4 RATING CRITERIA

The sufficiency rating method assigns a point rating to each section of road, based on its actual condition and its ability (or inability) to carry the traffic load in a safe and efficient manner. The "safe and efficient manner" is based on a uniform, current set of standards. The resulting tabulated ratings are used to develop a project priority list, without regard to geographical location or political influence.

Most of the systems developed to date have been done by state highway organizations. They have followed the same pattern and used the categories of Condition (sometimes referred to as structural adequacy), Safety, and Service. Items rated within each category are also similar from state to state. Table 1 represents a list of rating criteria commonly used in sufficiency rating systems.

TABLE 1

Commonly Used Rating Criteria

CATEGORY	ITEMS RATED*
Condition	Foundation*
	Wearing surface (or pavement)*
	Shoulder*
	Drainage*
	Remaining life*
	Maintenance economy*
Safety	Pavement width*
	Shoulder width*
	Stopping sight distance*
	Passing sight distance*
	Hazards
	Alignment consistency
	Traffic control
	Accident rate
Service	Alignment (or curvature)*
	Grade*
	Pavement (or surface) width*
	Passing opportunity*
	Improvement continuity*
	Ride quality (or rideability)*
	Surface type
	Shoulder width
	Alignment safe speed
	Surface volume to capacity

* Items generally used in sufficiency rating systems. Note: the list is a composite of criteria used by state highway organizations in Alaska, Arizona. Illinois, Iowa, Indiana, Maine, Missouri, Nebraska, New Mexico, Oklahoma, Virginia, and Wisconsin.

However, Oklahoma utilizes the general categories of Design and Condition, with criteria used for comparison similar to that of the categories of Safety and Service (Design) and Structural Adequacy (Condition).

Several criteria appear two times - under the categories of Safety and Service. Examples include passing opportunity (or safe passing sight distance), pavement width, shoulder width, and alignment. These criteria also appear under both categories in several rating systems as well, effectively increasing their impact on the final composite rating.

The rating system used by the Iowa DOT is typical of those used. It uses the three major common categories used, plus most of the rating criteria that are encountered. The list of criteria that are rated is shown on Table 2, together with the maximum points allocated to each.

There is one rating criterion that is unique, and that is "safety study". The criterion of "safety study" uses the result of a study of the frequency of occurrence of various types of road hazards along a given road segment. Included are such hazards as narrow structures, bad approach alignment to a structure, blind intersections, and railroad crossings without automatic signals.

An examination of this table also shows that surface width is rated twice. In addition, vertical alignment and horizontal alignment appear to overlap with stopping and passing sight restrictions, but they relate more to operat-

TABLE 2

The Iowa Sufficiency Rating System

RATING CATEGORY	ITEM RATED	MAX. POINTS
Structural:25	Wearing surface	7
	Base and subbase	7
	Drainage	3
	Maintenance economy	8
Safety:40	Surface width	17
	Shoulder type, width	9
	Stopping sight restrictions	8
	Safety study	6
Service:35	Horizontal alignment	8
	Passing sight distance	8
	Vertical alignment	6
	Surface width	8
	Surface driving conditions	5
	Total	100

Source: Iowa Primary Road Sufficiency Log - January, 1982 Prepared by Office of Advance Planning, Division of Planning and Research, Iowa Department of Transportation, Ames, Iowa.

ing speed. The rationale used to explain the second appearance of surface width is that a narrow surface is a safety hazard, but it tends to reduce capacity as well, a function of service.

2.5 RATING SCALE

The sufficiency rating given a road segment is a composite rating, in that it represents the sum of the scores given all criteria rated. Most rating organizations use a maximum composite rating of 100, with each criterion that is to be rated assigned a maximum value, depending on the relative importance given that rating criterion.

There are a few exceptions. The State of Illinois uses a 1000 point scale (1000 point maximum value), with maximum scores for the eleven rated elements ranging from 25 to 150 points. A similar 1000 point scale is used by Del Norte County, California (Nelson, p. 98). An unusual feature of this rating system is the inclusion of a rating element relating to type of traffic of up to 100 points. The further breakdown of this element demonstrates two unique features of the system. First, this element recognizes the existence of school buses, recreation vehicles, and forest product traffic in the traffic stream, and second, provides for maximum ratings of 20, 30, and 50 points, allowing for a rating scale more sensitive to individual variations -- without resorting to fractional points.

The Iowa system, summarized in Table 2, demonstrates how the rating maximum scores reflect current thinking on the relative importance of the rating criteria. While most of the maximum scores range from 5 to 8 points, surface width (included twice) can receive up to 25 points, while drainage is only 3.

An examination of rating scales used in other states shows the same variability in point values. While there are strong similarities in point values chosen for identical rating criteria, there are significant variations as well. For example, both Missouri and Wisconsin use Estimated Life as a rating criterion, with identical maximum values of 10 points. The two states also used a criterion relating to passing sight distance (Wisconsin used the descriptor non-passing zone), but Missouri allocated a maximum of 8 points, while Wisconsin used non-passing in two different categories, with a maximum possible total of 18 points.

Variations in rating formulae between states can be explained in two ways. First, there are differences in conditions existing in a given state, compared to others (Swanson, p. 11). The second relates to valid differences in opinions -- in the perception of relative importance. It is often described as empiric, or based on practical experience (Moskowitz, p. 29).

2.6 CONDITION RATING

Relative weights assigned to the various rating criteria cannot be determined entirely by deductive reasoning. Therefore, gaps in mathematically rational treatment of the problem have been bridged by empirical methods based on judgement and trial and error (Moskowitz, p. 29). Determination of the elements of sufficiency to be evaluated and the assignment of relative importance or weight to each element is the first step in development of a sufficiency rating system. The second step is to develop a method of computing or assigning a value to each criterion for the segment of road being rated.

The first system developed, the Arizona system, used the number 100 for whole sufficiency[3] -- for sake of convenience. The maximum value for each rating element is then assigned to a given rated road segment if it completely meets the standard set for that element. Should it not meet the standard, it would receive a lower score. Therefore, a graduated scale is needed.

The key to a graduated scale is the development of a standard for each rated element. The standard may vary with type of use, but still be considered "ideal" for that use. An example is shoulder width. An unpaved shoulder that is six feet (1.8m) wide may be the desirable width when Average Daily Traffic (ADT) is less than 400 vehicles per day (vpd). Therefore, a road segment with ADT less than 400 and a shoulder six feet (1.8m) wide should receive the maximum score for that rated element.

If the shoulder is less than the standard, then it properly would receive a lesser score. The immediate question would be "how much of the maximum score should the road segment receive?", but the larger question relates to all rated criteria. The answer is really in two parts.

The first part relates to the concept of "tolerability", and was included in the first sufficiency rating system. It works under the premise that (Fritts, p. 36):

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[3] Most sufficiency rating systems developed since have also used 100.

1. Not all road segments will meet the desirable standards for each rating element.
2. In some situations, the cost of the improvement of the rating element to meet design standards may not be justified (economically) compared to other needs.

This suggests that an element not meeting design standards might still meet a "tolerable" standard -- that it is less desirable, but still is safe, -- or provides good service. It also suggests that there is a "tolerable" standard value, that is at the lowest point on the scale permissible under today's highway transportation requirements. It is not determined by funds available, but rather is a point used to isolate and identify those road segments which are so far below design standards that their need for improvement is unquestioned.

The second part of the answer is concerned with scale calibration. Obviously, the beginning point is the maximum value for the rated element. Decreasing values are then set for road segments failing to meet the standard. Rate of decrease of points from the maximum could be either linear or exponential, depending on the rating element. Decisions on rate of decrease are normally made by developers of the rating system based on rating element characteristics and group consensus, based on experience.

Another variation in scale calibration can occur as the rating element drops below what is considered to be the "tolerable" limit. One approach is to evaluate the rated element until it reaches the tolerable limit, then assign it 0 points as it drops below that limit. Going back to the earlier example, a six foot (1.8 m) wide shoulder might receive the maximum of six points, a five foot (1.5 m) shoulder receive five points, and a four foot (1.2 m) shoulder four points. If the four foot (1.2 m) shoulder is considered the narrowest tolerable width, narrower shoulders would receive no points. On the other hand, points could merely decrease as the width narrows, with the intolerable element being regarded as a "warrant for action".

The concept of "warrant for action" is based on the standard set for a given element. Standards are based on the "hoped for" rate of meeting needs under the appraised fiscal capability of the involved governmental agency (Campbell, p. 86) and thus are economic based -- but not necessarily on the economics of the traffic using the facility. The existence of a critical deficiency is a warrant for action, without specifying the action. A "remarks" column records and quantifies the deficiency, naming the category and cause of the deficiency. The appropriate action is chosen by the engineer.

A "warrant for action" is not a priority listing, but shows the need for action. If money based, possibility of eventual action is assured. If not, critical deficiencies may proceed to a state of being only tagged "emergency". If standards are truly based on appraised fiscal capability, funds should be available to match the warrants over a reasonable length of time.

Many rating systems establish a numerical dividing line at some arbitrary point, such as 60, or 65, or 70, as the demarcation between adequate sections and those considered to be critically deficient. The final sufficiency rating automatically places a rated road segment in the adequate or critically deficient category. However, a closer examination of the priority list of projects assigned on the basis of sufficiency ratings may reveal that some road segments with ratings below the dividing line could be considered adequate because of the absence of critically deficient rating elements, while road segments with a sufficiency rating higher than that dividing line may merit a higher priority because of one decidedly critically deficient element.

Recognizing this problem, the State of New Mexico adopted a plan[4] whereby a road segment would be classified as critically deficient when a critical deficiency existed in any of its major characteristics. In effect, the critical deficiency becomes a "warrant for action", placing the rated road segment higher on the priority list.

The key to assignment of scores for the rated elements goes back to the need for reproducibility. For some rating elements, such as those relating to geometric design, this

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[4] The plan was outlined in its 1959 sufficiency report.

is comparatively easy. The shoulder width rating noted earlier is an example. All that is needed is some uniformity in gathering and recording of data. Other rating elements requiring some judgment are more difficult to reproduce. This is made easier by establishment of guidelines for the different ratings and easy-to-follow word descriptions. An example is the condition rating given a pavement section. Severity of failure can be related to a score by use of a word description closely matching the observed condition and applying the designated point value.

2.7 DESIGN STANDARDS - A SET OF SCALES FOR MEASUREMENT

Rating scales are based on two sets of standards. One is the value matched to the maximum value for a rated element. For the shoulder example, it is the six foot (1.8 m) width. In rating a given road segment, even a wider shoulder would not be scored any higher. The standard against which the rated elements are compared may be the design standards used for construction or reconstruction.

These design standards may be those for high-speed roads, using the blue book[5] or some other standard -- perhaps a state standard. The standards may vary according to the road's functional classification and/or ADT.

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[5] Geometric Design Guide for Local Roads and Streets prepared by the Committee on Planning and Design Policies of the American Association of State Highway Officials (AASHO).

The Iowa DOT provides such a set of standards. A total of 24 different design standards are used, with the variations being based on combinations of functional class, ADT, and type of terrain. Some of the changes are minor -- the only variation in design guides for the first six standards (freeway and expressway/arterial) are maximum degree of curvature (3 to 4), maximum grade (3% to 4%), shoulder type (paved to stabilized) and access control (from full to partial). A copy is included in Appendix E.

A similar set of design standards have been adopted by Del Norte County in California for its secondary roads. Its variations are based on ADT and terrain, with surface type specified for each standard -- based on ADT. Dissimilarity in terrain accounts for most of the differences between the Iowa design standards and the Del Norte County standards.

The U.S. Forest Service approached the problem of design standards from a different perspective. The Service recognized the fact that most roads in the United States are built using the same pavement design practices used for pavements carrying much larger volumes of traffic than the low-volume Forest Service roads. Further, it was noted that economic studies are not applied in the setting of design standards.

It was for this reason that the Forest Service contracted for a study to develop a pavement management system for its low-volume roads, and to include recommendations for the development of appropriate design standards. The rationale used to justify the study include the following factors (Hudson, etal, p. 232):

1. Low volume roads generally carry fewer vehicles per day than major highways, plus have lower loading frequencies.
2. Most of these roads are constructed with on-site or locally available material.
3. Funds and environmental factors permit only restricted earthwork on many low-volume roads, affecting horizontal and vertical alignment plus the ability to remove and replace poor subgrade material.
4. Surfaces of low-volume roads tend to be thinner than that of higher class roads (in the case of hard-surface roads) or consist of nothing more than a gravel or natural soil surface.
5. Because of the nature of the surface material, performance of low-volume roads is influenced to a greater extent by moisture and temperature than higher class roads.
6. Distress problems differ, related to surface materials. For example, surface abrasion leading to dust problems and loss of surface material are more acute on gravel surfaces than on asphaltic concrete surfaces.

7. Minimum acceptable level of serviceability is lower on most low-volume roads than that of higher class roads. This is because the purpose of the road is to provide an economical means of travel from point to point, not so much to provide a smooth riding surface.

This rationale applies to low-volume secondary roads as well, and has lead to numerous calls for development of design standards more appropriate for secondary roads (Baerwold, p. 41; Carlson, p. 2 p. 23), or perhaps reversion to older standards (Harrington, p. 48).

The other set of standards used in the development of rating scales is a set of "tolerable" standards. Setting tolerable standards is an empirical process, based on an evaluation of past design practice and the resulting investment. They are set by informed engineering judgment, using as a goal the definition of existing investment that can be continued in use without creating;

1. congestion detrimental to public welfare,
2. low operating speeds which could lead to unnecessary economic time losses,
3. unreasonable accident rates,
4. unreasonable maintenance costs, and/or
5. higher than necessary operating costs due to circuitous routes, excessive grades, or poor surfaces.

It is unfortunate that there is a lack of information which could be used as guidance in developing tolerable standards, particularly for secondary roads. There have been studies which can assist in this endeavor, at least for some elements. One such study has shown a strong negative correlation between sufficiency ratings and accident rates (Jorgensen, pp. 114-117). This study showed a significant increase in accident rates between the best highways (ratings over 80) to the poorest highways (ratings under 50). The relationship of increase of accidents was linear as the sufficiency ratings of rural highways dropped to 50 for two of the three states studied.[6]

This study (and other studies conducted since) began to pinpoint specific design elements that affect highway safety, in terms of relationships between design elements and accident rates. Elements such as pavement lane width, shoulder width, and horizontal alignment have been shown to have a significant effect on highway safety and design guidelines have been suggested, based on study results (Bissell, etal, pp.1-15).

However, most of the studies have used data from accident records on rural primary highways and have limited applicability on roads carrying less than 1000 vpd.

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[6] The third state involved in the study lacked data for some comparisons.

It would appear that the setting of tolerable standards, at this time, will remain mostly an empirical process, with the potential for some assistance from applicable studies. One likely set of empirical standards would be the "minimum standards" of a set of design standards.

2.8 DATA NEEDS

A large share of the data needed for a sufficiency rating can be gleaned from an up-to-date set of records of the design plans used to build the rated road segment. This can be verified by an examination of any set of criteria used in a sufficiency rating system.

An example is the list of the rating criteria used by the Iowa DOT in preparing sufficiency ratings for the state's primary roads (see Table 2). Of the categories of Safety and Service, only the results of the safety study and data on surface driving conditions cannot be obtained from design plans. However, all of the rating criteria under the Structural category must be evaluated from historical knowledge of the road segment and/or an analysis of the current condition of the various elements of this category based on a field inspection.

Examination of other rating systems will reveal similar data needs (Baerwold, pp. 51,52; Table 1 of this report; Moskowitz. pp. 30,31; Donnell and Tuttle, pp. 65-69; Zegeer and Rizenbergs, pp. 15-19; and Nelson, pp. 98,99). It is therefore apparent that any sufficiency rating system used will require a combination of data which should be permanently on file and situational data gathered expressly for the evaluation.

2.9 TYPICAL SYSTEMS IN USE

Most of the literature on sufficiency rating systems dates back to the years following Arizona's development of its system. In those years, many states developed similar rating systems of their own for use in evaluating their network of primary highways. The emphasis was on the evaluation of primary highway systems, although there were some efforts to apply the concept to secondary roads.

Literature in recent years has been strongly oriented toward the development of a successor to sufficiency ratings for primary highways. To this end, several procedures have been developed, though none have been widely adopted. They all are computerized procedures, designed to take advantage of the computer's speed and flexibility.

They include two procedures developed by the Federal Highway Administration (FHWA); the Priority Planning Procedure (PRIPRO) and the Highway Investment Analysis Package (HIAP). To date, PRIPRO has not been used in any state, but HIAP has been used in Wisconsin and is being considered for use by New Mexico and Idaho (Humphrey, p. 9). The Priority Planning System (PPS) was developed by the Ontario Ministry of Transportation and Communication and is being used by that province to manage a large highway investment portfolio. It is also being used by the Maryland DOT, but only for large capital projects. The Highway Economic Evaluation Model (HEEM) was developed by the Texas State Department of Highways and Public Transportation as a priority planning tool and has been used extensively by that state.

Though none of these models have achieved wide acceptance, another model, a formalized pavement management system (PMS) is gaining proponents. In a way, it is not new. Every highway agency has established a management system. The main difference is that PMS provides feedback concerning the consequences of decisions made on priorities and technical details. Feedback enables decisions to be made with knowledge of the consequences of given trade-offs.

Some sort of PMS has been established in nine states and two Canadian provinces, though not the complete and comprehensive PMS form described in NCHRP Report 215 as the "ideal" PMS. The users of PMS consider it a good analytical tool for one category of improvements that can be used in establishing overall priorities, though not the ultimate solution to priority planning needs.

Some literature is available that describes sufficiency rating systems in place, including a few systems used for evaluating secondary roads. The literature pertaining to the evaluation of secondary roads is briefly summarized below.

2.9.1 Del Norte County, California

In 1966, Del Norte County was faced with a severe problem in the form of inadequate funds for road improvements. Its annual road improvement budget of about $200 000 was less than half the amount needed to solve road deficiencies over the next ten years. There was an obvious need for a way to establish priorities for the use of available funds.

A list of seven criteria was developed for the improvement program (Nelson, p. 98).

1. The program would have to be comprehensive. All pertinent road features would have to be known, and the most important road uses established.
2. It would have to be understandable to the average taxpayer and the Board of Supervisors as well as to the professional engineer.
3. It would have to be economical.
4. The program would have to identify road improvements by priorities, including cost considerations.
5. Separate priorities would be required for the major system of roads and the minor system.
6. Field and office work would have to be performed primarily by maintenance personnel and/or engineering technicians, rather than by engineers.
7. The program would have to lend itself to being regularly updated as improvements were made and as traffic features changed.

The resulting road improvement program was based on priorities set with the aid of a road sufficiency rating system. A dual rating system was developed, based on functional class. One was applicable to collector and arterial roads (slightly less than 20% of the total county highway mileage) and the other to local roads and streets.

The rating system developed was similar to the Arizona[7] system, with service receiving 35% of the rating points, safety 35%, and structural adequacy 30%. The Del Norte County rating system used a 1000 point scale instead of the 100 point scale commonly used and rating elements more appropriate for use in evaluating secondary roads. The complete rating system is shown on Table 3, listing the rating elements and points allocated.

Unique features of the rating system includes recognition of the relative importance of traffic type to the road network (school bus, forest products, and recreation traffic), accident rate, remaining life, and maintenance economy. Consideration of the traffic type element is in recognition of the unique economic base of the county, and its dependence on the lumber industry and tourism. The rating elements of accident rate, remaining life, and maintenance economy are used because of their perceived importance to the evaluation system and the availability of excellent records for all three elements.

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[7] Arizona's system used 35, 30, and 35 for the respective categories.

TABLE 3

Sufficiency Rating System - Del Norte County, California

	MAXIMUM POINTS	
	Collectors and Arterials	Locals
SERVICE: 350		
ADT	150	150
School Bus (20)		
Forest Products (50)		
Recreation (30)	100	100
Passing Opportunity	40	--
Surface Condition	30	50
Type of Surface	30	50
SAFETY: 350		
Accident Rate	100	--
Traveled Pavement Width	100	150
Shoulder Width	50	100
Horizontal Alignment	50	50
Vertical Alignment	50	50
STRUCTURAL ADEQUACY: 300		
Drainage	100	100
Remaining Life	100	100
Maintenance Economy	100	100
Total	1000	1000

The county adopted a set of design standards for its roads prior to the first rating, in order to determine the existence and extent of deficiencies in the road network. A copy is included in Appendix E.

2.9.2 Kings County, California

Kings County began development of a procedure for establishing relative adequacy and priority scheduling upon receipt of the results of a 1953 study of the county's road system. This study concluded that the deficiencies in its road system would cost an estimated $6 million to correct. This greatly exceeded the county's fiscal capability, causing the administration to seek a way to develop priority schedules for road improvement programming that would maximize benefits for all concerned (Carlson, 1955, p. 21).

Administrators felt it was needed to (Carlson, 1953, p. 131);

1. aid the administration in budgeting, based on economic priority,
2. compare each section of road evaluated to its design standards,
3. minimize the element of personal judgment in determining the relative adequacy of a road,
4. keep the Board of Supervisors apprised of the current status of the road improvement program,
5. determine the rate of progress of the road improvement program,
6. aid in explaining the road improvement program to the public, and
7. make it possible to match fiscal capability to definite road standards.

Actual priority determination was made using the sufficiency ratings and an economic analysis. Highest priority for road improvement would be the road segment theoretically considered to be the least adequate with the highest economic justification. Even so, the established ratings were considered to serve only as guides in the development of road improvement programs.

Design standards were developed for the roads, based on the ADT carried by the road. The standards were very similar to those adopted by the County Engineers Association of California. The minimum standard was for roads carrying less than 50 vpd, while the highest standard was for roads carrying 1000 to 4000 vpd. A copy of the standards is included in Appendix E.

The rating elements chosen were similar to those used by other rating systems, with some variations due to local conditions (most of the roads are straight and on flat terrain) and the fact that over 75% of the road mileage carried less than 400 vpd. A total of four rating categories were chosen, with maximum points ranging from 15 to 40 for the categories. A complete list of categories and rating elements is shown in Table 4, together with their maximum points . Ratings were determined by uniform and rational methods (Carlson, 1955, p. 23).

The rating category of Physical Design Adequacy is very similar to Condition in other rating systems, while the category of Service provides an adjustment to the rating based on the relative importance of the rated road segment to the community. Relative importance is based mostly on the type of traffic using the road and its function in connecting communities or highways as opposed to local service.

TABLE 4

Sufficiency Rating System - Kings County, California

CATEGORY	ITEM RATED	MAX. POINTS
Geometric Design Adequacy	Right-of-way width	5
	Roadbed width	10
	Surface width	10
	Gradient	5
	Alignment	5
	Stopping sight distance	5
Physical Design Adequacy	Surface	10
	Foundation	10
	Drainage	5
Safety	Accident factor	5
	Alignment consistency	5
	Maximum safe speed	5
Service	Route Classification	10
	Community service	10
	Total	100

2.9.3 Allen County, Indiana

County highway departments in Indiana faced financial problems similar to that of Kings County and Del Norte County in California. The problem of budgeting available funds was addressed in the development of procedures for the classification and evaluation of rural highway sections by the Joint Highway Research Project of Purdue University in 1954. The procedures were tested in a pilot study conducted in Allen County, Indiana (county seat - Fort Wayne). Allen County had the greatest county road mileage in the state, a total of over 1500 miles (over 2400 km).

A road rating system was developed, along with a service rating system, and used to compute a priority rating, based on a formula developed as part of the project. The priority rating concept was based on the premise that, given a constant road rating, the priority rating should increase as the service rating increases. This would mean that, should two roads be evaluated equally in terms of adequacy ratings, the one with the highest service rating should receive the highest priority for improvement.

The service rating was based on the "need" for service and was computed using the factors of volume and character of traffic, abutting land use, and the use of the rated road for community services, such as rural mail service, school and/or scheduled bus routes, and other community services. The road rating system was a sufficiency rating system using the evaluation categories of structural adequacy, geometric design, and safety.

The priority system developed was deemed to have the following desirable properties (Baerwald, pp. 38,39):

1. Roads which provide a minimum service should have a priority ranking which approaches a minimum, regardless of condition.
2. Roads with a high road (sufficiency) rating should have a priority ranking also approaching a minimum, regardless of service provided.
3. For a constant service rating, rate of change of priority rating should decrease as the road (sufficiency) rating decreases.

4. For a constant road rating, rate of change of the priority rating should increase as the service rating increases.

Therefore, the priority system built in the concept of higher standards for more intensive road use.

The road rating system begins with determination of the primary use of a given highway, to be utilized in its classification as a county primary, county secondary, or local service highway. Classification was carefully done, so as to minimize the mileage in the county primary and secondary system. Because of limited funds, mileage of routes requiring higher design standards was to be limited.

The classifications, similar to current functional classes of trunk, trunk collector, and area service, were primarily based on ADT. Highways with ADT in excess of 400 vpd were considered for the county primary classification, while those with ADT of 100 to 400 vpd were generally considered to be county secondary. Those with ADT of less than 100 were usually classified as local service.

County highway classifications were assigned, using the criteria developed. Initial classification resulted in about 12% of the county highway mileage being classified as primary, 11% secondary, and the remainder as local service. Although over 75% of the highway mileage was classified as local service, no location in the county was over 2.5 miles (4 km) from a state highway or a county primary or secondary highway.

Recommended design standards were developed for each classification, with minimum and desired standards suqqested for each component of the set of standards. A copy of these standards is provided in Appendix E. They were set with the expressed goal of establishing a practical standard, balanced with economy of operation.

The rating system was based on the evaluation of three categories of rating elements -- structural adequacy, geometric design, and safety. The complete list of rating elements is shown on Table 5, but not including maximum points.

TABLE 5

Sufficiency Ratings for Secondary Roads -Indiana

RATING CATEGORY	ITEM RATED
Structural adequacy	Pavement type
	Pavement condition
	Roadside drainage
	Structures
	Railroad grade crossings
Geometric Design	Right-of-way
	Pavement width
	Shoulder width
	Gradient
	Alignment
Safety	Surface riding condition
	Shoulder condition
	Safe driving speed
	Stopping sight distance
	Passing sight distance

2.9.4 Kentucky Secondary Roads

In 1976, Kentucky updated its sufficiency rating system (last revised in 1963) to incorporate the latest engineering principles, design standards, and the use of the computer (Zegeer and Rizenbergs, p. 16). New descriptors were included to make evaluation of rural and urban highways more meaningful.

The current rating system contains modifiers to make it possible to evaluate all rural highways, both primary and secondary, and to make meaningful comparisons of the adequacy ratings in both systems. This was accomplished through the use of different design standards for the two systems, based on a combination of design speed and traffic volume. For example, a shoulder two feet (0.6 m) in width would receive the maximum of seven points if it was on a highway carrying less than 100 vpd, while a 12 foot (3.7 m) shoulder is required to receive the seven points if the highway carried an average of 1500 to 7000 vpd.

Adequacy rating elements were taken from the list of commonly used elements from a nationwide survey published in 1973. The rating elements used in the Kentucky system were chosen based on the results of a subjective evaluation of elements from that list. The adequacy rating elements recommended are listed in Table 6, for use with rural highways only.

TABLE 6

Sufficiency Rating System for Secondary Roads - Kentucky

RATING CATEGORY	ITEM RATED	MAX. POINTS
Condition	Foundation	10
	Pavement surface	10
	Drainage	8
	Maintenance economy	7
Safety	Stopping sight distance	8
	Alignment	8
	Skid resistance	7
	Accident experience	12
Service	Shoulder width, condition	7
	Passing opportunity	8
	Rideability	5
	Surface width	10
	Total	100

Note: This table is applicable only to rural highways.

The rating system features guides with word descriptions developed for use by field personnel to aid in evaluation. Graphs are provided for the evaluation of some elements, generally based on traffic (ADT) using the rated highway segment. A copy of the guide is included in Appendix E.

The system also features the use of the computer to determine and provide the results as printed output. The only input into the computer program is the raw data for each highway section. The output for each rating is in a neat, easy-to-read, summary format.

2.9.5 A Sufficiency Rating System for Iowa Secondary Roads

A dispute between a group of residents and the local County Board of Supervisors over priorities in the road improvement program provided the impetus for development of a sufficiency rating system for secondary roads in Iowa in 1960. Although the rating system was never widely accepted, the rationale used in its development is of interest, as well as the final suggested form.

The choice of rating elements and characteristics for inclusion was principally based on (Morris, pp. 48,49):

1. Their simplicity.
2. Their facility for ease of measurement and direct comparison with correspondent values in the standards of assumed "complete adequacy" for each element of the involved highway.
3. Their close association with the obvious reasons for reconstructing or otherwise improving a highway.
4. The importance of their influence on the quality of traffic service provided by the highway.
5. Their degree of tangibility and accessibility to the public and to highway officials for their observation and examination.
6. Their ease of comprehension and evaluation by non-technical staff personnel and highway officials responsible for administration of secondary roads.

7. Their close association with the central theme of the definitions of sufficiency rating as they appear in the glossary of HRB Special Report 62.

Sufficiency rating systems used by other states for secondary roads were examined for potential use in Iowa. However, none were found to be suitable because of;

1. number and complexity of factors,
2. emphasis on factors which are relatively insignificant on roads with small traffic loads, and
3. lack of emphasis on factors most directly and closely related to serviceability of a road to traffic.

The process of developing an appropriate list of rating elements included a careful examination of sufficiency rating systems already in use. The rating elements chosen and their relative weights emphasized the structural category, as can be seen by an examination of Table 7, showing the rating elements and maximum points which could be allocated. The "range" of maximum points which the roadway pavement and the roadway base could receive depended on the materials used. Portland cement concrete pavement could receive as many as 24 points, while asphaltic concrete pavement could only receive a maximum of 16 points. A rolled stone base could receive a maximum of 10 points, but a bituminous treated base could receive as many as 17 points.

No point totals are shown on the table, since the maximum points could vary. Maximum ratings under this system could range from 115 to 130 points.

TABLE 7

Sufficiency Rating System for Secondary Roads - Iowa

RATING CATEGORY	ITEM RATED	MAX. POINTS
Structural Characteristics	Roadbed width	13
	Pavement width	12
	Shoulder width	8
	Ditch depth	8
	Pavement type, thickness	16 or 24
	Base type, thickness	10 or 17
	Subbase depth	8
	Snow storage capacity	5
	Gradient factor	3
	Alignment factor	2
Structural Condition	Roadbed condition	5
	Pavement condition	5
	Shoulders - condition	5
	Ditches - condition	5
General Services	Number of homes	5
	Mail route	2
	School bus route	3

The design standards used for the system were the "Farm-to-Market Road Design Standards, January 1, 1960" as adopted by the Iowa State Highway Commission. A copy can be found in Appendix E. The design standards were based on ADT, with three ranges included. These were 0 to 100, 100 to 400, and 400 to 1000 vpd. Each traffic load category had two sets of standards, a minimum standard and a recommended standard.

A single standard was chosen for the rating system, the recommended standard for 400 to 1000 vpd. The rationale used for this choice was

> -- on the assumption that these standards would provide superexcellent service for traffic volumes under 100 vpd, excellent service for between 100 and 400 vpd, and good service for between 400 and 1000 vpd.

The basic sufficiency rating of the rated highway segment was adjusted by application of a traffic volume adjustment. The equation suggested was developed by the Arizona Highway Department and used to provide a higher priority to those roads carrying higher traffic volumes.

2.9.6 Washtenaw County, Michigan

The Michigan legislature passed a highway act in 1951 which required county road commissions to report mileage and conditions of all highways and structures annually. Reporting the mileage was fairly routine, although the initial report was a time-consuming and tedious job. However, the condition report was more of a problem, since there was little that could be done to substantiate the data in the report without a more complete and formal adequacy survey.

Therefore, an adequacy rating study was initiated to enable the county to meet state reporting requirements. Study objectives were for an adequacy rating system to:

1. Aid in assigning priorities for reconstruction, by comparing each highway segment to a set of prescribed standards.
2. Minimize (or eliminate) the element of personal judgment in the assignment of ratings.
3. Evaluate a road's ability to carry traffic quickly, safely, and economically.

4. Minimize political pressure on the development of planning and construction programs.
5. Keep officials advised of the current status of their highway program.
6. Measure progress in eliminating road deficiencies.
7. Compare one road with another.

A set of design standards was developed, using U. S. Bureau of Public Roads (BPR) and Michigan State Highway Department standards, modified to fit county traffic needs. Final adopted standards were established for four different road designs, based on ADT. Standards were for Group 1 - 0 to 100, Group 2 - 101 to 500, Group 3 - 501 to 1000, and Group 4 - 1000 to 4000 (Minier, p. 42).

The sufficiency rating system that was adopted used the 100 point scale and the three rating categories of condition (par 35), safety (par 30), and service (par 35). Table 8 shows the full list of rating elements used, together with the maximum number of points allocated.

Graphs and tables were set up to help determine the point value of such elements as remaining life and passing opportunity. The sum of all ratings applied to a given road segment was referred to as its "basic rating".

Two adjustments were made to the basic rating to determine its adequacy number. The first adjustment was made for traffic volume and the second applied to roads with granular surfaces. The final adjusted rating for a section of road,

TABLE 8

Sufficiency Rating System - Washtenaw County, Michigan

RATING CATEGORY	ITEM RATED	MAX. POINTS
Condition	Pavement condition	10
	Subbase and drainage	12
	Remaining life(pavement)	13
Safety	Shoulder width	8
	Pavement lane width	7
	Stopping sight distance	10
	Consistency (alignment)	5
Service	Alignment	12
	Passing opportunity	8
	Rideability	10
	Pavement width	5
	Total	100

called its adequacy number, was the sum of its basic rating, the traffic adjustment, and the granular surface adjustment.

The traffic adjustment was made from traffic data gathered for each road and a set of curves constructed according to a method devised by the BPR. Roads carrying traffic in excess of 250 vpd received negative traffic adjustment scores, while roads carrying lighter traffic loads received positive scores.

Granular surface adjustments were made on all roads with a granular surface carrying more than 100 vpd. Deductions were made (on a straight-line basis) of up to 10 points as ADT ranged from 100 to 200.

2.10 CONCLUSION

Sufficiency rating systems have been considered useful tools for priority ranking in the development of road improvement programs. Even though they have been used mostly for evaluation of primary roads, there have been many instances of satisfactory use for secondary roads.

There has been some movement to replace sufficiency ratings with a more sophisticated numerical analysis procedure to aid in decision-making, but this is not because of any gross problems with the rating system. Rather, it is in recognition of its limitations plus the availability of a variety of data relating to such things as maintenance costs, life expectancy, and data relating to the impact of types of traffic on roads. One factor causing this movement is the easy availability of the computer and its value in rapidly accessing road data and its fast response, enabling decision-makers to explore several possible courses of action before settling on one.

The fact that no successor has been widely accepted and that sufficiency rating is still used by most states says much about the system. It is still useful as a decision-making tool and has the potential for wider use by county administrators. Counties have many of the same problems that state highway administrators face and sufficiency ratings can serve the same purposes (Campbell, p. 79).

A sufficiency rating system can provide the appropriate rating criteria, weighted scores, and graduated numerical scoring necessary to compare the relative adequacy of one road segment against another. Criteria can be chosen to fit local variations and perceived levels of importance.

It is also fairly easy to adjust rating values for type and extent of use, recognizing that it is more important to improve a road carrying 500 vpd than one carrying 50 vpd, other factors being equal. This has been achieved by the use of different design standards for different roads and/or modifiers applied to the computed rating before establishment of priorities.

Developers of a new sufficiency rating system do face a series of problems.

1. Choice of the list of rating elements is subjective. However, it can be attained by some sort of consensus among the affected decision-makers. It is subjective, but user experience can narrow the list of possible criteria to a usable one which will yield acceptable results.
2. Choice of relative weights (importance factors) of each criterion is also subjective, but the same consensus can still be achieved. Individual users of the system can vary the weights to attain internal goals.

3. Choosing appropriate design criteria to meet may cause problems, particularly as decisions are made on how to correct for variations in use. On the other hand, this problem has been successfully faced by developers of other rating systems, and the results will provide guidance for new systems.

The greatest problem to be faced is how to devise a system that is usable, yet not too complicated. It is likely that potential users of a new sufficiency rating system will face some of the same problems that the earliest users faced, and that is the lack of data, or data not being in usable form. It does appear that this problem can be solved. The remainder of this document will describe the process used to develop the new system, describe the results, and show how it can be used.

Chapter III

THE PROBLEM

While there has been work done on numerical evaluation systems for secondary roads, none are directly applicable to Iowa's network of secondary roads. There are enough differences between Iowa's network and the road systems evaluated using those results to preclude direct application. On the other hand, there are undoubtedly some elements that are pertinent to Iowa's situation, and these should be isolated and included (in applicable form) in any proposed system for Iowa counties.

There are several questions that need to be addressed by this study. They are based on the assumption that a numerical evaluation system that will accurately describe the adequacy of roads in a county network is necessary or at least desirable. They are summarized briefly below.

1. Are the roads classified (divided into groups) according to importance or purpose logically, so that a rational basis can be established for priority of improvement and standards to be achieved?
2. What relationship should exist between design standards and an adequacy evaluation system? Can selection of the set of design standards help produce a better sufficiency rating system?

3. What evaluation elements are appropriate to rate secondary roads?

4. What weight should be applied to each of the evaluation elements? Does failure to meet the tolerable standard suitably represent the road's ability to serve its desired function?

5. What road system data are available? What additional data will be required for the proposed evaluation system?

This research project represents an attempt to answer these questions. Volume 2 of this report will describe the procedures followed to find the answers and the answers.

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