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PILOT PROGRAM FOR EVALUATION OF STRUCTURAL ADEQUACY OF FLEXIBLE PAVEMENTS FOR COUNTIES AND MUNICIPALITIES

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16. Abstract

Using presently available technology, methodology was developed for evaluating flexible pavement on a system basis. It was hoped that the results could be used for setting more realistic load restrictions and designing and programming improvements on a priority basis. Data were collected on about 125 miles (200 km) of roadway in each of three counties and on about one mile (1.6 km) of street in each of six municipalities. Data consisted of a traffic study and a structural study.

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INVESTIGATION NO. 650

PILOT PROGRAM FOR EVALUATION OF STRUCTURAL ADEQUACY OF FLEXIBLE PAVEMENTS FOR COUNTIES AND MUNICIPALITIES

Final Report 1980

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In Cooperation With
MINNESOTA LOCAL ROAD RESEARCH BOARD

FOREWORD

This study was conducted to develop a methodology for pavement evaluation on a system basis. The results can be used for setting more realistic load restrictions and designing and programming improvements on a priority basis.

The project was included in the program of the Minnesota Local Road Research Board as a project of interest to County and Municipal Engineers and was funded with County and Municipal State-Aid Research Funds.

The author wishes to express his appreciation to the many individuals whose cooperation, assistance and advice made the conducting of the project possible.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

SUMMARY

OBJECTIVE

The Minnesota Local Road Research Board established this study to develop a methodology for pavement evaluation on a system basis. The pavement evaluation was to use the technology currently available in Minnesota. It was hoped that the results could be used for setting more realistic load restrictions and designing and programming improvements on a priority basis. Three counties, Clay, Washington and Wright, were selected to furnish about 125 miles (200 km) each for evaluation. Six municipalities were included shortly after the study began and each furnished one street of about one mile (1.6 km) in length.

SCOPE

The pavement evaluation consisted of a traffic study and a structural study. The traffic portion was designed to be quite extensive in order to gain more information about traffic characteristics on county and municipal roads. The structural portion consisted of the collection of office and field data concerning pavement cross-section and age plus field data on pavement deflections and servicability.

The traffic analysis resulted in a new set of seasonal distribution factors, vehicle class distribution factors and truck factors for low-volume roads and daily Standard Axle Load (SAL) applications for each pavement section in the study. The structural analysis consisted of the calculation of allowable spring axle loads and remaining life estimates.

SUMMARY OF FINDINGS AND CONCLUSIONS

The following is a list of the more important findings in this report:

1. The spring axle load capacity is higher than the posted spring axle load limits on 46.9 percent of the sections evaluated and could be considered for increased posted limits.

2. New seasonal distribution factors, vehicle class distribution factors, and equivalent Standard Axle Load truck factors were established for low-volume roads.

3. Future pavement evaluation of this type (structural and traffic analysis) would require about ten person hours per mile (1.6 km) of pavement.

4. The inplace pavement thickness is generally greater than indicated on the plans or other office information.

5. The remaining life estimates made with the data available were not very good. The major item required for better life predictions is a serviceability history. Future serviceability measurements on a periodic basis (one to three years) would provide this history.

RECOMMENDATIONS

The following is recommended:

1. The counties and municipalities adopt the pavement evaluation system described under Investigation 645 (given in Appendix C) using the traffic factors recommended in Appendix A and the cumulative distribution method for calculating allowable spring axle loads described in this report.

2. New labor saving devices be utilized for pavement deflection measurements.

3. Mechanical aids for conducting vehicle classification counts be developed or found.

4. The computer availability for the counties and municipalities be determined and, if practical, a computerized data anaysis, recording and reporting system be developed.

INTRODUCTION

Developments in pavement technology, by Mn/DOT and others, have resulted in a number of pavement evaluation procedures. These procedures can be used to assist the engineer in objectively assessing such pavement characteristics as structural adequacy, serviceability or ride characteristics, and even expected life. However, there has been limited use of pavement evaluation techniques by the counties and municipalities. The reason for the limited usage of these evaluation techniques has been the lack of personnel and equipment together with an unfamiliarity of the methods and their benefits.

In an attempt to broaden the usage of these techniques, the Minnesota Local Road Research Board (LRRB) project "Pilot Program for Evaluation of the Structural Adequacy of Flexible Pavements for Counties and Municipalities" (called the "Pilot Project" for the remainder of this report) was proposed at the Board's spring meeting in 1975. A work outline was prepared and approved at a special meeting on August 19, 1975.

The content of the "Pilot Project" is best described by the first two sections of the work outline as follows:

I. THE PROBLEM

Many Minnesota counties and municipalities face an urgent need to evaluate the load-carrying capacity of their flexible-type pavements. This need stems from the fact that insufficient data are available to set realistic spring load restrictions and to design bituminous overlays and other road structure improvements for providing an adequate load-carrying capability consistent with the traffic served. The benefits accruing from having such information available have direct economic implications. First, load restrictions would be modified, in some cases, to benefit of the traffic served. In other situations more accurate load restrictions would protect public investment in the road structure. Secondly, with better knowledge of the existing load-carrying capability, structural improvements could be more accurately programmed and designed, thus avoiding the consequences of underdesign and the wastefulness of overdesign.

Originally, most of these roads were designed to structural standards rated in terms of axle load limits for an expected range of traffic volumes. These standards were based on a background of information accumulated over the years combining research findings, experience and a variety of emperical design procedures. While these standards served well for design guidance, there was wide latitude in the structural capability of any one category depending on relative exposure to traffic axle loadings as well as differences in soil and environmental conditions. These old standards have now been superseded by design techniques based on more recent research involving the concepts developed at the AASHO Test Road as modified for Minnesota conditions. The procedure in terms of performance is supported by a series of field strength tests relating load-applied surface deflection measurements to road structure and a greatly improved characterization of truck traffic in relation to fatigue of the road structure.

Considering the new design technique, the by-product capability afforded by its input requirements, MHD Investigation 603, "Flexible Pavement Evaluation With the Benkelman Beam," and MHD Investigation 630, "Deflection Study of Flexible Pavement Overlays," valuable tools are available for assessing existing flexible pavement structure, and determining remaining service life. The basic ingredients necessary are deflection measurement surveys and appropriate traffic data to ascertain the composition of the heavy-commercial-average-daily-traffic component supplemented by identification of the existing bituminous thickness. A statewide program could provide an invaluable data bank of information for the use of local road highway administrators permitting them to make more practical decisions in setting load restrictions, developing a program of scheduled improvements, or for designing improvements. Since a statewide program would be a substantial and costly under-taking, a pilot project could be advanced to develop format, procedure and cost data that could be applied to the more comprehensive program.

The objective of this program is to develop a methodology for counties and municipalities to use in evaluating flexible pavements as applied to the setting of more realistic load restrictions and the designing and programming of improvements on a priority basis. To this end Clay County, Washington County, and Wright County would participate in a pilot project. The pilot project would consist of evaluating approximately 125 miles of county roads chosen by the respective county engineers in each of the three counties and would consist essentially of two main phases: data collection followed by analysis and interpretation. The aim would be to develop and document procedure that would serve as a guide in applying the techniques to a statewide program. From the data analysis it is expected that road structure strength could be ascertained in terms of current load-carrying capacity and remaining service life. Inherent in the process would be the identification of structural strengths and weaknesses and a means of more accurately designing and programming improvements to upgrade load-carrying capacity. The cost of the pilot project in terms of time, manpower and equipment would be documented with the expectation of deriving unit costs useful in estimating the cost of a statewide program for this type of evaluation.

Three counties, Clay, Washington and Wright, were involved in the "Pilot Project". Each county selected about 125 miles (200 km) of County State Aid Highways to be included in an evaluation which consisted of traffic, pavement strength, and serviceability information. Six municipal streets were included in the project in the fall of 1976. These were Municipal State Aid Streets, each of about one mile (1.6 km) in length. The municipalities involved are Blaine, Brooklyn Center, Fridley, St. Louis Park, South St. Paul, and White Bear Lake.

The traffic data, pavement deflections, structural thickness, and pavement serviceability (roughness and surface condition) information required for the "Pilot Project" make up the major components that are needed for pavement evaluation and a pavement inventory system. The data collection was done by Mn/DOT with assistance from the respective counties or municipalities. The data collection effort represented the most costly portion of the study.

The analysis of the data was a joint effort between the Traffic Forecast Section of the Policy and Planning Division and the Physical Research Section. The Traffic Forcast Section did the traffic analysis; these results are contained in two reprots which are shown as Appendix A:

1) SPAR S-251
   Summary of Traffic Data Gathered for the Pilot Program for Evaluating Flexible Pavements on Local Roads (Inv. 650)

2) SPAR S-251A
Summary of Traffic Data Gathered in Municipalities for the Pilot Program for Evaluating Flexible Pavements on Local Roads (Inv. 650)

The Physical Research Section then used these data to calculate the allowable spring loads and to estimate the remaining life of the pavement before it becomes a candidate for rehabilitation. These data could be used to choose the best rehabilitation procedure for the pavement, which could range from a thin overlay to complete removal and replacement. There are no formal or standardized procedures available in Mn/DOT at this time to design a rehabilitation based on inplace pavement characteristics.

DATA COLLECTION

The purpose for data collection on this project was threefold. The first purpose was to evaluate the pavement. The other two were to determine the effort and cost involved to collect the data and to determine how extensive the data collection effort must be for meaningful results.

There were four major categories of data that were collected as shown in Table 1.

Table 1. Data collected for the "Pilot Project."

Category	Collecting Agency
1. As built history	Local
2. Traffic	Mn/DOT and Local
3. Structural	Mn/DOT and Local
4. Serviceability	Mn/DOT

The collection of the data was a joint effort shared by Mn/DOT and the county or municipality (local) as shown in Table 1. Each of these categories will be treated in a separate section.

AS-BUILT HISTORY

The information concerning the pavement structure (thickness and composition), subgrade type and condition, date and placement and other relevant information such as traffic and spring load limits make up the "as-built" history for the "Pilot Project". The collection of these data was accomplished by sending a form to the participating agencies which was filled out by them and returned. The form was devised specifically for the "Pilot Project" and is shown in Figure 1.

For future projects of this nature, tabulation of office information should be the first step. However, the form shown in Figure 1 should be discarded and replaced with one similar to that shown in Appendix B. Such a tabulation allows quick easy access to the general pavement information by route and location. Also, the tabulation can be used to plan the field data collection based on need. The field data collection should be done with respect to the project termini and other factors such as changes in traffic or structure. With knowledge of the above information, a general testing plan can be established in advance.

The age of a pavement, along with the engineer's general knowledge of its condition and traffic, should be considered in placing priorities on what field data is collected first. Eventually, as the missing and critical areas are filled in, a schedule of data collection could be established which would provide a basis for determining the on-going performance of the pavements.

Pilot Program for Evaluation of the Structural Adequacy
of Flexible Pavements for Counties and Municipalities

Investigation 650

Planned Structure and History of County Roads

County Highway Designation ______________________ County ______________________

Termini ____

Date Constructed ______________________

Soil Classification* ______________________

Subbase ______________ in. Material Class ______________

Base ______________ in. Material Class ______________

Surface ______________ in. Spec. No. ______________

Overlay:

Date ______________ Thickness ______________ in. Spec. No. ______________

Present Spring Restriction ______________________________________

Comments:

*For soil classification, any information you may have may be helpful i.e. AASHO, Unified or just Plastic, Semi-Plastic, or Non-Plastic

Figure 1. Forms for gathering the structural "as-built" history.

TRAFFIC

For the purpose of pavement evaluation, it is necessary to know how many trucks use the pavement and how much they weigh. Recent findings by Mn/DOT have also shown that the seasonal distribution of the truck traffic has a definite bearing on pavement life. An expression that quantifies the traffic that occurs or will occur on a pavement is just as important as the information on the pavement structure and subgrade on which it rests. Without knowledge about the level of traffic, adequacy of the pavement structure strength cannot be determined.

Because the traffic on a pavement represents such a wide variety of vehicle types which can run anywhere from empty to overloaded, some method is needed to reduce the traffic to a single number. Such a method was developed through the AASHO Road Test at Ottawa, Illinois and has been since verified by a number of agencies. The traffic ideally is reduced to an accumulation of equivalent Standard Axle Loads (previously called N18's) by applying an equivalency factor to each axle that passes over the pavement and then summing the results. (A Standard Axle Load or SAL is a dual-tire, single-axle weighing 18,000 pounds or 80 kn.) Since it is practically impossible to measure the weight of every axle that uses a pavement (unless a Weigh-in-Motion installation is used) a method to estimate the SAL accumulation has been developed.

To obtain an SAL estimate, samples of the traffic volume (AADT), vehicle distribution, and vehicle weights are needed. Detailed procedures to do this are presented in Sections .523 and .524 of the Mn/DOT Road Design Manual and are also described in a series of presentations to the counties and municipalities by Dr. E. L. Skok under Investigation 645 and summarized in Appendix C. (Investigation No. 645 is a LRRB research implementation project established in 1974.) The traffic portion of the "Pilot Project" involved the field collection of AADT, vehicle class distributions, and vehicle weights for all four seasons of the year (except that winter vehicle weighings were not done). The traffic data was analyzed by the Traffic Forcast Section of the Planning Division and is described in two System Planning Analysis Reports, S-251 and S-251A, included in Appendix A. The daily SAL application for each of the county roads in the "Pilot Project" was also furnished by the Traffic Forcast Section and is listed in the Data Summary Appendix (Appendix B) and for the Municipal streets in Report S-251A.

The traffic data for the "Pilot Project" was gathered through the combined efforts of the county, the traffic engineers in the Detroit Lakes, Golden Valley, and Oakdale districts, and the Field Data Unit in the Planning Division. The counties did the vehicle classification counts; the districts did the vehicle counts; the Field Data Unit did the loadmeter (vehicle weighing) work.

The traffic data gathering for the "Pilot Project" required a substantial effort in person hours (see section on costs, page 20) because it was designed to provide information beyond that required for a normal traffic study. The normal method of establishing an SAL value, as described in .523 and .524 of the Road Design Manual, only involves a 48-hour traffic count and a 16-hour vehicle class count, then relying on established factors for seasonal corrections and truck factors. Much uncertainty existed about the seasonal distribution of the heavy-commercial traffic on low-volume roads and the weights of the heavy-commercial vehicles.

It was decided by the Traffic Forcast Section that it would be necessary to establish the foregoing factors based on an actual low-volume road traffic study. This study would then be of benefit to the other counties with traffic patterns similar to one of the three counties involved. The traffic report (SPAR S-251) recommends that "no more counties be surveyed as a part of this project." The traffic analysis procedure described in section .523 or .524 of the Road Design Manual or in Dr. Skok's presentation describe alternates to some of the steps, such as using a traffic flow map instead of doing a 48-hour traffic count. Other data gathering methods, such as the fall season vehicle weighing in Clay County and described in Appendix A, may eliminate the need of vehicle weighing if one type of vehicle is dominant such as the sugar beet trucks. The Clay County example used the dominance of sugar beet hauling to demonstrate how vehicle weights can be determined without weighing. This was done with the excellent cooperation of the Crystal Sugar Company in Moorhead. Crystal Sugar weighs each truck that delivers sugar beets, records its origin and stores the information in computer files, thus allowing access without a large investment in man hours. With some imagination the same approach can be made on any road that serves a specialized purpose. For instance, the U.S. Forest Service can keep track of the loads applied to some of its pavements by the board feet of timber harvested from an area served by the road. County roads that serve specific purposes, such as agricultural, quarry, land fill, etc. and municipal streets that have an MTC route or serve a specific industry, lend themselves to evaluation without intensive vehicle weighing or counting. If the local user agrees to source or destination weighing or can furnish weights, an estimate of the SAL accumulation can be made. There have been problems with this approach in the past because of fears that the information will be used for enforcement of vehicle weight laws. To efficiently maintain a road system, knowledge of goods movement is essential, and efforts should be made to open information channels that do not have the threat of enforcement.

Knowledge of the use of a local road is emphasized because of the non-regularity of that use. An example is the fall weighing in Clay County. If that season's use alone were used as being representative of the SAL accumulation on those roads, the estimate would be excessive. Conversely, the summer weighings would have resulted in an underestimate in the SAL accumulation prediction. As the heavy commercial traffic increases in volume, the day to day or season to season variation in volume tends to decrease.

STRUCTURAL

This portion of the "Pilot Project" was conducted to determine the strength and composition of the pavements. The field work consisted of two parts, auger borings and Benkelman Beam deflection measurements taken at about 500-foot (152.4 m) intervals for all the roads in the project.

The auger borings were done by Mn/DOT District Soils Engineers personnel in the Detroit Lakes, Golden Valley, and Oakdale districts. Traffic control was provided by the counties. When resulting holes in the roadway were patched by the flag men, the auger crew could proceed at a faster rate.

The function of the auger borings was to determine the thicknesses and composition of the road structure layers and to classify the underlying soil. Borings were taken to a depth of four feet (1.2 m) (one auger flight). The layer identification was limited to the total bituminous layer, aggregate base layer, and their respective thicknesses. The underlying embankment soils were classified by texture. (These data are listed in Appendix B.) The textural classification system is described in the Grading and Base Manual 5-692.611. Estimates were made of the subgrade R-value based on the textural classifications. The layer thickness and composition were used to estimate a pavement Granular Equivalent (GE) thickness based on a unit GE of 2.0 for biutminous and 1.0 for aggregate base.

The Benkelman Beam deflections were run by the counties with the help of one man from the district office to provide assistance or training in Benkelman Beam deflection measurement operation. Deflections were taken in the vicinity of the auger borings. Washington County used a commercially built beam with a 4 to 1 beam ratio while Clay and Wright counties used Mn/DOT-type beams, the latter having built their own device. The deflection measurement procedure used is described in Investigation No. 603, 1968 Summary Report "Flexible Pavement Evaluation with the Benkelman Beam". The procedure used to calculate the allowable tonnage in the spring is not the same as that described in the report; the method of tonnage calculation is described in detail in the analysis section of this report.

SERVICEABILITY

The term serviceability is used to describe how well the pavement can serve the user. Normally it is associated with a rating of some sort which varies from one agency to another but yet similar in most respects. In Minnesota the serviceability is assigned a value from 0 to 5 as follows:

- 5 Very Good
- 4 Good
- 3 Fair
- 2 Poor
- 1 Very Poor.

A normal assigned rating to a newly constructed pavement is in the range of 4.0 to 4.5 whereas a value of 2.5 considers the road to be in need of some sort of repair. This leaves an operating range of only 2.0 units for normal pavement serviceability; however, since it is expressed in tenths, it results in about 20 different assignable levels of serviceability for a normal pavement.

The serviceability and surface condition was rated by the respective District Materials Engineer's office for Clay and Washington Counties. This information for Wright County was not accomplished because of scheduling difficulties and availability of personnel. The lack of this information for Wright County does not detrimentally affect the overall objectives of the project.

The performance of a pavement is determined by the change in serviceability over a period of time. The rate of decline in serviceability is affected by the SAL accumulation on the pavement. As a portion of the "Pilot Project", the serviceability level was to be measured on all of the involved roads. The procedure is described in the research report for Mn/DOT Inv. 189, "Development of a Rating System to Determine the Need for Resurfacing Pavements". The serviceability measurement involved a roughness measurement with the PCA Roadmeter on each pavement segment and a surface condition rating of a random quarter-mile segment for each mile of road. The Present Serviceability Rating (PSR) is obtained by measuring the pavement roughness with a PCA Roadmeter. The Structural Rating (SR) procedure involves applying weighted factors to the measured distresses and combining them mathematically. For adaptation to the "Pilot Project" concept for the counties and municipalities, the procedure developed by Dr. E. L. Skok, and presented in Inv. 645 appears more applicable for the pavement condition survey portion. That procedure keeps track of the individual types of distresses that are independently more revealing of a pavement condition than an SR composed of weighted distress values. It also reduces the calculation time required.

The roughness measurement, as done with the PCA Roadmeter, involves measuring the accumulated differential movement between a car body and its rear axle over the entire length of the road. The total accumulated movement is averaged over the length of the measured segment and a resulting roughness of inches per mile is converted to a Present Serviceability Rating (PSR). [The relation between roughness in inches per mile and PSR is determined annually by a calibrating panel for the Roadmeter assigned to the Research Section. The remaining Roadmeters are then calibrated against the Research Roadmeter.]

ANALYSIS

After the collection of the office and field data, various analyses were done, with the final result being the tabulation shown in Appendix B. This tabulation is a summary of all the structural, age and traffic data, the calculated allowable spring tonnage, and an estimate of remaining life. The weakest portion of the analysis is the estimated remaining life because the serviceability was measured at only one point in time. As more points are obtained, a declining serviceability trend can be established which in turn can be used to predict when the serviceability will decline to a terminal level. (A terminal serviceability level is the serviceability at which some improvement is needed. A commonly used value is a PSR of 2.5.)

The analysis of the traffic for the "Pilot Project" required an estimate of the SAL application for each section. Other information obtained from the traffic portion of the "Pilot Project" that is of general benefit to the other counties and municipalities are the seasonal distribution factors, vehicle equivalency factors, and a description of some alternate methods that can be used for obtaining traffic estimates.

The analysis of the structural portion of the "Pilot Project" resulted in allowable spring axle loads for each pavement section and an estimate of pavement life when used in conjunction with the SAL estimates from the traffic analysis. The strength of the pavements was calculated by the methods described in Inv. 603, "Flexible Pavement Evaluation with the Benkelman Beam". The calculation procedure was modified somewhat to allow a rating by using the cumulative distribution of individual tests instead of being based on the mean-plus-two-standard-deviation deflection as described in Inv. 603.

Serviceability describes a pavement's characteristics at some point in time. Pavement history, as described by age or traffic and serviceability, makes up the information required to describe the performance of the pavement. The performance of a pavement is defined as the rate of change of serviceability. This rate of change is influenced by the combined effect of two items, traffic and structure. The rate of change of serviceability with the pavement age enables an estimate to be made of the remaning life of the pavement. A record of the serviceability history will allow an improved estimate of remaining life to be made by projecting the past serviceability trend to a chosen terminal PSR such as 2.5.

TRAFFIC ANALYSIS

The analysis of all the traffic field data that was collected required a substantial effort as shown in Table 5 in the next section. Because the traffic portion of the "Pilot Project" was designed to give information on seasonal distributions and SAL factors by vehicle class, it involved a lot more work than a conventional traffic study. The tabulation and coding for computer entry of four seasons of information required the equivalent of about four person years of work. The results of the analysis of the traffic data are described in the SPAR reports in Appendix A. [The details of how such a specialized analysis was conducted is not of interest to this report because of its uniqueness. It is not something that will be done in the routine evaluation of any pavement or system in the future. However, the Traffic Forcast Section could continue to monitor the value of the factors if, in the future, a copy of all the traffic data collected by the counties and municipalities were forwarded to Mn/DOT through the District Traffic Engineers (author's speculation at this time.).]

The "Pilot Project" effort, coupled with other low volume road data that has been collected by Mn/DOT, has resulted in a set of factors which can be used with a fairly high degree of confidence to produce SAL estimates for county roads.

Almost secondary to the traffic portion, but prime to the subject of pavement evaluation and the overall theme of the "Pilot Project", is the calculation of the daily SAL applications for each pavement section. The SAL information allows pavement life estimates to be made. Without SAL estimates pavement life estimates can only be made after establishing a serviceability trend with time.

For those counties and muncipalities interested in pursuing the "Pilot Project" techniques, the procedure for gathering SAL information can be obtained from sections of the Road Design Manual (.523 or .524) or from the handouts given to the county and municipal engineers by Dr. Skok as a part of Investigation 645. The effort required to gather and analyze the data for SAL estimates has not been documented by this project but can be estimated fairly accurately. The analsyis effort can be aided through use of small programmable calculators or computers, reducing the hours required for normal manual calculations.

STRUCTURAL ANALYSIS

The field data from the Benkelman Beam deflection measurements and from the auger borings are used to determine the strength of the pavement in terms of allowable spring axle loads; they also can be used to aid in the performance estimates for the pavement when used in conjunction with the traffic (SAL) and age information.

A comparison of the planned and measured thicknesses of the road structure layers was made for each county by determining the average and standard deviation of the planned and measured layer thicknesses of all of the sections in the "Pilot Project". The section-by-section planned and measured thicknesses were also correlated with each other. The higher the correlation coefficient (r^2) the better the agreement between the office data and the field data. The comparisons showed that the inplace pavement is generally thicker than the office files show it to be. The agreement between the planned thickness versus the measured thickness varied from county to county. The importance of this is that the pavements could be slightly stronger than they are thought to be. It also shows that the confidence placed on the planned thickness varies from county to county. For future "Pilot Project" work, the amount of auger borings needed could be sharply reduced if there were confidence in the planned values. The results of the comparisons are shown as (planned thickness/measured thickness) in inches (1 inch = 2.54 cm) as follows:

		Clay	Wash.	Wright
Surface	Average	3.10/3.96	3.64/4.76	2.37/3.77
	Std. Dev.	2.02/1.84	1.99/1.45	0.80/1.73
	Corr. Coef.	0.81	0.34	0.06
Base	Average	9.49/12.01	8.25/10.02	8.70/8.99
	Std. Dev.	2.27/2.33	4.19/3.48	2.55/3.84
	Corr. Coef.	0.62	0.11	0.13

The information available on newer jobs may be more reliable; however, that supposition was not checked. In Clay County, where it was found that the thickness was quite uniform, the auger boring spacings were increased to 1000 foot (304.7 m) intervals.

The evaluation of the deflection and thickness data followed a portion of the method described in Investigation 603 "Flexible Pavement Evaluation with the Benkelman Beam," Summary Report 1968. The procedure used is as shown in Table 5 of that report, except that the tonnage is calculated by each point rather than by the mile based on the average-plus-two-standard-deviations deflection. The allowable tonnage on a point by point basis is then evaluated by the cumulative distribution technique. The engineer can then select an allowable spring loading to protect a chosen percentage of the road being evaluated. This has been found to be a more acceptable method than the mean-plus-two-standard-deviations method because many of the pavements have deflections that are not normally distributed in a statistical sense. For the purpose of the "Pilot Project", the "measured tonnage" in the tabulation was chosen at a level such that 85 percent of the individual points are stronger than the "measured tonnage". The 85 percent value is not a recommendation of this report but is used for illustration since it approximates the tonnage of the mean-plus-one standard-deviation deflection if the deflections are distributed normally. (This is a commonly-used value reported in many papers on pavement management.) The level of protection for a pavement should be chosen to match the needs of the road authority, the condition of the road, and the needs of the user. The 85 percent level can, for example, be chosen for collector routes. A 90, 95, 97.5 or even a 99 percent level could be chosen for other routes, depending on their relative importance. This option is mentioned not to set a standard, but to open up the choices available for a pavement management system. The consequences of choice must be understood, e.g. a setting of 85% may require a greater overlay budget in the future while a 99% level may require a greater user cost because of the additional trips required due to lower axle load limits.

The tonnage evaluation on a point by point basis was calculated as follows:

$$La = 9 \left[\frac{ABB}{(BB + TCF) \times SCF}\right]$$

where:

La = Allowable spring axle load
BB = Benkelman Beam deflection
TCF = Temperature correction factor
SCF = Seasonal correction factor
ABB = Allowable Benkelman Beam deflection.

This relationship can be solved manually in a tabular form as was done for the "Pilot Project" or can be programmed into a computer for handling large amounts of data. The correction factors for temperature and season and allowable Benkelman Beam deflection are taken from Inv. No. 603, "Flexible Pavement Evaluation with the Benkelman Beam", Summary Report 1968 and are listed in Tables 2, 3 and 4.

Table 2. Benkelman beam deflection corrections to the standard temperature of 80F. *

Range of Defl. in Inches	Temperature in Degrees F				
	to 35	36-45	46-55	56-65	66-75
.000 - .010	.005	.004	.003	.002	.001
.010 - .020	.007	.006	.004	.003	.001
.020 - .030	.010	.008	.006	.004	.002
.030 - .040	.010	.008	.006	.004	.002
.040 - .050	.012	.010	.007	.005	.002
.050 - .060	.015	.012	.009	.006	.003

*All corrections to be added.

Table 3. Allowable spring Benkelman beam deflections.

TRAFFIC	two-way HCADT*	<50	50-100	100-300	>300
	two-way ADT**	<500	500-1000	1000-3000	>3000
	one-way ADSAL***	<10	10-20	20-60	> 60
Bituminous Surface Thickness		Allowable Deflections, inches			
less than 3 in.		0.075	0.070	0.060	0.045
3 to 6 in.		0.065	0.060	0.050	0.040
greater than 6 in.		0.055	0.050	0.040	0.035

*HCADT = heavy commercial average daily traffic volume (excludes passenger cars and 4-tired trucks).
**Use ADT only when HCADT or ADSAL is not known.
***ADSAL = average daily Standard Axle Loads.

The Allowable Axle Loads (La's) are then tabulated by individual test position and a spring axle load restriction, if required, can be chosen from the tabulation by the cumulative distribution method to protect as many points as desired. This tabulation is also useful for future reference. A strength profile can be made indicating whether there are localized weak areas that can be corrected to upgrade the overall route. When strengthening of the entire overall route is not necessary, correcting localized weaknesses may represent a substantial cost savings compared to placement of a complete overlay.

A general relationship from Investigation 630, "Deflection Study of Flexible Pavement Overlays", states that each inch of bituminous mixture decreases the deflection by about 10 percent. This can be used as a rough guide for overlay thickness design to achieve the desired strength. This relationship is most effective on pavements that have deflections that are in the range normally expected on a typical bituminous roadway. It will not provide satisfactory results if applied to pavements having poor subgrade support conditions.

Table 4. Deflection ratios to calculate critical spring deflections from deflections taken during other non-frozen times of the year.

PLASTIC EMBANKMENTS

Asphalt Surface Thickness (inches)	Sept.	8/16 8/31	8/1 8/15	7/16 7/31	7/1 7/15	6/16 6/30	6/1 6/15	5/16 5/31	5/1 5/15
≤ 2	1.76	1.72	1.68	1.63	1.57	1.52	1.44	1.35	1.17
> 2 ≤ 3-1/2	1.74	1.73	1.69	1.64	1.60	1.55	1.47	1.34	1.17
> 3-1/2 ≤ 5-1/2	1.72	1.73	1.68	1.60	1.52	1.45	1.39	1.26	1.16
> 5-1/2 ≤ 8	1.50	1.47	1.39	1.31	1.28	1.25	1.24	1.24	1.16
> 8 Conventional Construction	1.41	1.30	1.22	1.16	1.13	1.13	1.16	1.16	1.13
> 8 Full-Depth Construction	1.51	1.45	1.38	1.17	1.02	1.03	1.14	1.21	1.17

SEMI-PLASTIC EMBANKMENTS (L, Sil, and sl. pl. SL)

Asphalt Surface Thickness (inches)	Sept.	8/16 8/31	8/1 8/15	7/16 7/31	7/1 7/15	6/16 6/30	6/1 6/15	5/16 5/31	5/1 5/15
≤ 2	1.91	1.87	1.83	1.78	1.72	1.67	1.54	1.45	1.27
> 2 ≤ 3-1/2	1.89	1.88	1.84	1.79	1.75	1.70	1.57	1.44	1.27
> 3-1/2 ≤ 5-1/2	1.87	1.88	1.83	1.75	1.67	1.60	1.49	1.36	1.26
> 5-1/2 ≤ 8	1.65	1.62	1.54	1.46	1.43	1.40	1.34	1.34	1.26
> 8 Conventional Construction	1.56	1.45	1.37	1.31	1.28	1.28	1.26	1.26	1.23
> 8 Full-Depth Construction	1.66	1.60	1.53	1.32	1.17	1.18	1.24	1.31	1.27

NON-PLASTIC SOI (S, S & G, FS, and LFS)

Asphalt Surface Thickness (inches)	Sept.	8/16 8/31	8/1 8/15	7/16 7/31	7/1 7/15	6/16 6/30	6/1 6/15	5/16 5/31	5/1 5/15
All Thicknesses	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.10	1.05

NOTE: Critical deflections correspond to maximum deflections which occur in the spring, during which the pavement is most likely to be damaged by heavy loads.

The above data is taken from Investigation No. 183.

PERFORMANCE

An important portion of the "Pilot Project" is the capability to predict pavement life (performance). Performance, for the purpose of this report, is defined as the change in serviceability with SAL applications or time. Therefore, performance can be used to determine when a pavement will be a candidate for an overlay or some other type of rehabilitation. Planning and budgeting becomes easier if pavement performance can be predicted for at least five years into the future.

The performance was predicted by two different methods. One was to assume a PSR level of 4.2 at the time of the last surfacing (age 0) and graphically plot a line between the assumed PSR at age 0 years to the measured PSR at the age of measurement as shown in Figure 2. This line can then be extended to a PSR of 2.5. The age of the pavement at a PSR of 2.5 minus the age at measurement is then an estimate of the remaining life for the pavement.

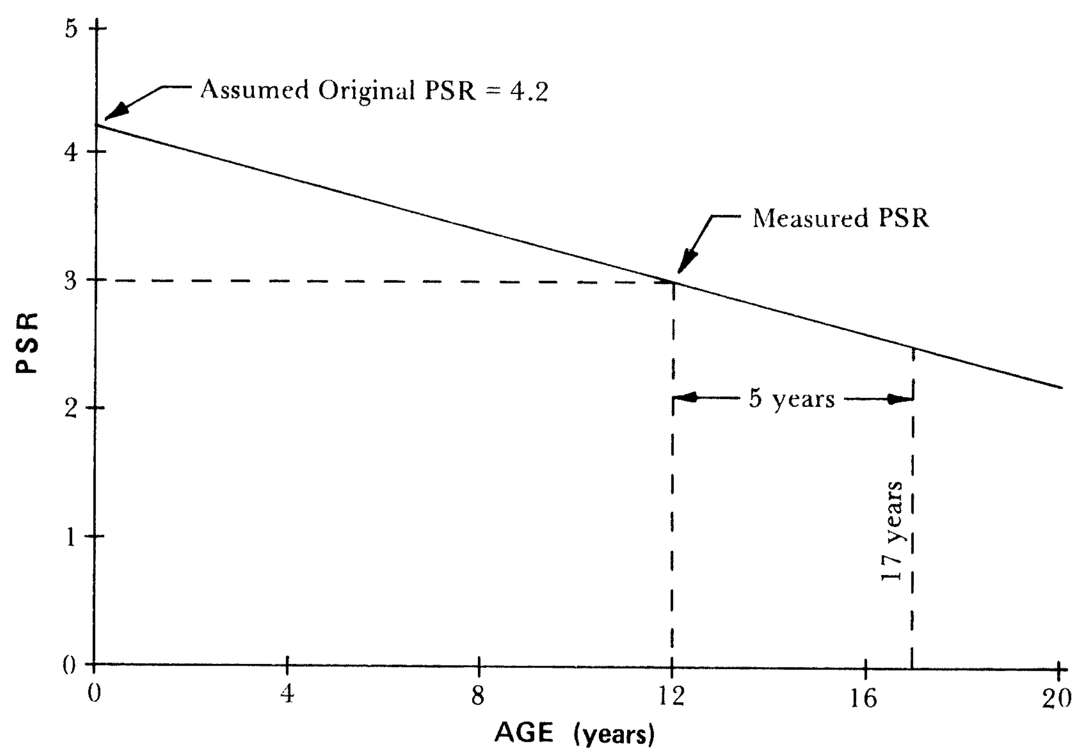


Figure 2. Graphical method of estimating pavement life.

There are several problems with this analysis. The first is the assumed original PSR which was chosen to be 4.2. The second is the use of a single PSR measurement. To be effective, the PSR should be measured at about three-year intervals to establish a good trend. The interval can be adjusted to suit the needs of the road. With several measurements of the PSR available, a better graphical relationship than a straight line can be used to forecast future PSR's. A model found to be a good predictor of PSR's in Inv. 183 is the Irick Performance model:

$$\text{Log}\,(\text{ASALt}) = A + B \times \text{Log}\,(\text{Log}\,(\text{PSRo}/\text{PSRt}))$$

where:

ASALt = Accumulated Standard Axle Loads of time t.
PSRo = Original PSR
PSRt = PSR at time t.

To be fairly accurate there should be several points to fit this model to also.

The second method of predicting performance involves the calculation of the SAL capacity of the pavement based on the Benkelman Beam deflection. With the age of the pavement known, the SAL application rate, and the traffic growth factor, the remaining life can be calculated.

By observing the tabulation in Appendix B, it can be seen that neither performance prediction method looks very good. The serviceability method tends to underpredict life remaining, and the deflection method tends to overpredict pavement life. Subsequently, a third method was developed, using both the PSR and Benkelman Beam deflections. With the knowledge of the present SAL, a rate of PSR decline can be predicted. That rate can then be applied to the most recent PSR to determine when a PSR of 2.5 is expected. To accomplish this, the decline in PSR and the accumulation of SAL's were correlated for all 58 Investigation 183 test sections. This rate of decline was then correlated to the Benkelman Beam deflection. The relationship used is as follows:

$$\text{slope} = 0.00000036 \times \text{ADSAL} \times \text{BB}^{2.2}$$

where:

slope = dPSR/YEAR
ADSAL = Average Daily Standard Axle Loads
BB = Benkelman Beam deflection (inches) x 1000

A graphical illustration of how the remaining life can be estimated is shown in Figure 3.

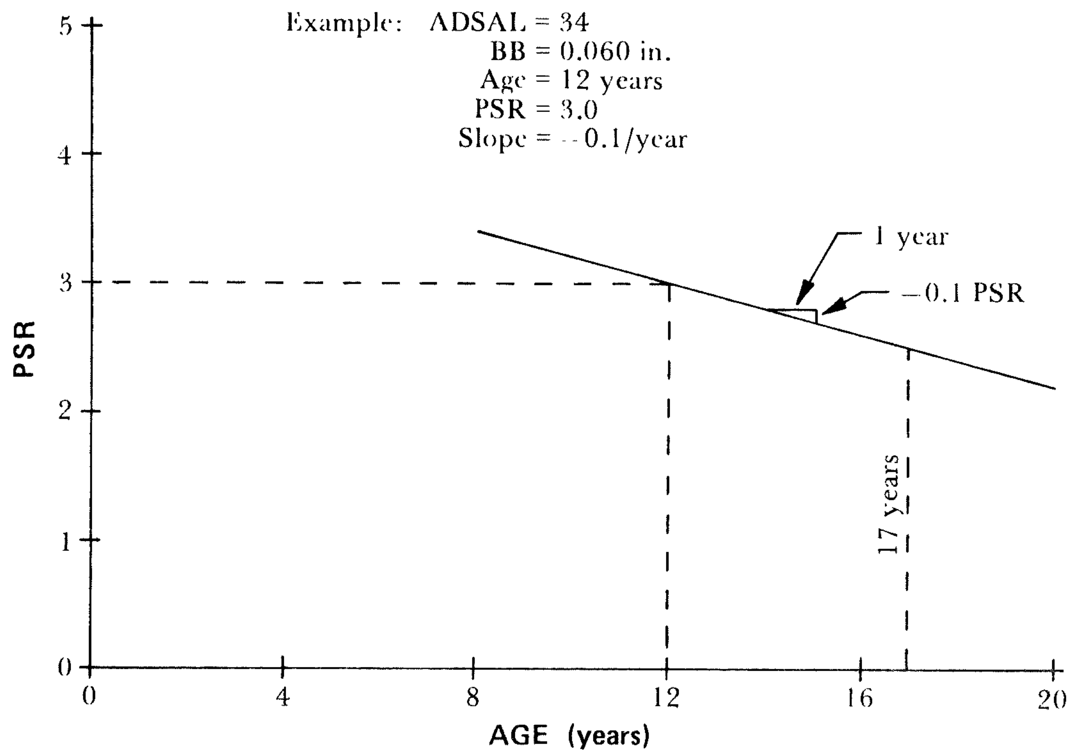


Figure 3. Remaining life estimate.

The graphical illustration assumes a zero growth rate in traffic. The following relationship can be used to account for a future traffic growth rate.

$$\text{Years} = \frac{\ln\left[i\left(\dfrac{\text{PSRo} - 2.5}{3.6 \times 10^{-7} \times 365 \times \text{ADSAL} \times \text{BB}^{2.2}}\right) + 1\right]}{\ln(1+i)}$$

where:

Years	=	Remaining life predicted
PSRo	=	Observed PSR
BB	=	Measured Benkelman Beam deflection (in. x 1000)
ADSAL	=	Average Daily Standard Axle Loads
i	=	Traffic growth factor i.e. 4% = 0.04

This method can be used to estimate remaining life if there is no serviceability trend and can be used as a check when there is a serviceability trend available. A further refinement can be made to account for the seasonal distribution of the ADSAL if the seasonal distribution of SAL's is available.

ANALYSIS RESULTS

The following is a list of the direct results of the "Pilot Project":

For all counties and municipalities:
1. Improved seasonal correction factors for low-volume roads
2. Improved truck factors for low-volume roads

For the involved counties and municipalities
1. Pavement thickness and subgrade type profiles
2. Traffic -- AADT, HCADT, and SAL
3. Pavement strength profile
4. Spring axle load capacity by section.

From the direct results of the "Pilot Project", pavements or pavement routes can be sorted and future improvement or maintenance projects can be prioritized by any of the values such as traffic, strength, age or some combination of traffic, strength, and age. Overlay design can be established based on traffic need and spring axle load capacity, and can be varied to match the pavement strength profile by placing thicker overlays in the areas of higher deflections.

If the three counties in the "Pilot Project" were considered typical of the counties in Minnesota, similar studies of this type would result in an increase of the posted allowable spring axle load for much of the mileage involved. Of the 388 miles in the "Pilot Project", 182 miles or 46.9% could be considered for an increase in the allowable spring axle loads. This type of information would reduce the amount of expense of overlay work required to upgrade a system to all 7 or 9 ton routes.

TIME ANALYSIS

An important part of the "Pilot Project" is to assess the imput effort expended in obtaining the data and applying the procedures. This is best expressed in person-hours rather than dollars. Hour requirements will enable local agencies to make better cost estimates of similar undertakings by applying their current cost factors (wages) to the hour requirements. There was such a wide range of people involved in the various tasks that a tabulation of the cost by task would be hard to interpret for future estimates.

Table 5 lists the hours spent for each task by each county separately and the municipalities collectively. Since only a limited amount of work was done in each municipality, these data were grouped together.

Table 5. Tabulation of person-hours by activity and agency.

	Time (hours)			
Task	Clay	Wash.	Wright	Municip.
Traffic Counts	260	300	383	30
Vehicle Class Counts	1600	940	1100	90
Weighing	2340	2070	2475	—
Analysis (Traffic)	TOTAL	8000		
Auger (3 people)	360	410	~400	50
Benkelman Beam (4 people)	560	390	~600	50
PSR & SR	100	50	—	10
Analysis and Report	TOTAL	1350		

The hour requirements for the traffic phase were quite high, particularly for the weighing. Future projects of this nature would not require as much effort since the "Pilot Project" established many of the factors required for future traffic estimates which are based on a 48-hour vehicle count and a 16-hour vehicle classification count.

The structural phase of data gathering involved an overall average of 7.5 person-hours per mile (1.6 km) of road. Equipment time requirements can be roughly estimated at one hour per mile (1.6 km) for auger borings and for Benkelman Beam deflection measurements. The light vehicles and roadmeter charges are normally accounted for by the mile and are simply estimated by the overall mileage of future work.

By utilizing currently available equipment, or developing new equipment, many man-hours can be saved, particularly in deflection measurements and vehicle class counts. Modern deflection measuring equipment can cover up to 40 miles (64.4 km) per day at the same test intervals as in this study with the Benkelman Beam and with only a two-person crew. This is much faster than the Benkelman Beam, which averaged from 7.0 miles (11.3 km) to 9.5 miles (15.3 km) per day with a crew of at least four people. Vehicle class counts require a large time investment per vehicle on low-volume roads. Although the experience with the Model 401 Streeter-Amet Traffic Classifier was unsucessful, mechanical classification or mechanically-aided classification is possible and should be developed. Vehicle weighings also requires a large amount of person-hours per vehicle weighed. Several weigh-in-motion devices are now becoming available; however, the high capital investment makes them unattractive for low-volume roads. Methods of gathering weight information at the source or destination result in significant time savings and greater safety; these should be pursued whenever possible.

The time spent for analysis on the "Pilot Project" was also greater than the time an agency would be required to spend to implement this type of pavement information monitoring since much of the analysis done for this report does not have to be repeated by the local agencies.

FINDINGS AND CONCLUSIONS

To manage the pavements in a road system, information is needed that describes the pavement age, composition and strength, together with information describing the traffic in terms of volumes and axle weights. The "Pilot Project" was conducted to determine the effort required to gather such information, the type of information needed, and the benefits provided by such information.

The conduct of the "Pilot Project" involved the use of existing technology, so no creative research was done. It did, however, result in the modification of some of the existing analysis methods and traffic factors. There were two principal areas of effort, traffic and structural.

The findings and conclusions of the traffic portion of the project are described in Appendix A, but the major points are two fold:

1. That no further intense traffic studies are needed.

2. That SAL estimates can be made by using the standard procedures described in the Road Design Manual or by Dr. Skok in Investigation 645, except the seasonal distribution factors and SAL factors established in this project should be used.

Based on the first conclusion, the time or cost of the traffic portion would have little value for future reference. The time and cost requirements for gathering the traffic information required to manage a pavement system would have to be estimated on an individual basis.

The auger borings have shown that there is generally a thicker pavement section inplace than records indicate. The comparisons of the actual thickness to the indicated thickness show that the correlation of the two can vary from very poor to good from county to county.

The strength of the pavement, when considered with the SAL volume, has shown that a number of roads evaluated can be considered for an increase in the allowable spring axle load limits. The reason the strengths are higher than expected relates mainly to the quality of the subgrade. Whenever there is any doubt concerning the subgrade strength, the lower value is assumed. Benkelman Beam deflection tests measure the actual inplace strength of the pavement and the subgrade. The analysis of the deflection data and structural data indicated that the spring axle load capacity of the inplace structure is higher than the posted load limits on 46.9 percent of the pavements involved.

The time requirement for the structural phase of the "Pilot Project" was about 7.5 person-hours per mile (1.6 km) of pavement. The traffic, using a 48-hour machine count, and a 16-hour vehicle classification count, would occupy approximately another 2.5 person-hours per mile (1.6 km). The total time requirement then would be in the range of 10 person-hours per mile (1.6 km) of pavement evaluated. At an assumed wage of $10.00 per hour, 100 miles (161 km) of pavement would cost $10,000 to evaluate. That cost, considering the benefits, is a good investment.

RECOMMENDATIONS

There are definite and identifiable benefits of a "Pilot Project" - type program. The participating counties and municipalities are encouraged to continue the work, and other counties and municipalities are encouraged to adopt such a system. They can either do the work or have it done by consulting firms that perform such a service.

The procedure used should be that presented by Dr. Skok under Investigation 645 (Appendix C) with the following exceptions:

1. Traffic factors developed under the "Pilot Project" be used.

2. Allowable spring axle load limits be chosen from the cumulative distribution of the allowable loads that are calculated on a point by point basis.

An estimate of the remaining life can be made based on the daily Standard Axle Load applications, annual growth rate of the Standard Axle Loads, spring Benkelman Beam deflections, and the present serviceability of the pavement.

Time savings for data collection can be realized by using currently available non-destructive testing equipment in lieu of the Benkelman Beam. There was an evaluation of a mechanical traffic classifier (Streeter-Amet Model 401) in conjunction with the Washington County vehicle classification counts which showed that the mechanical classifier was not acceptable for use on low-volume roads. However, recent developments may have resulted in a realiable mechanical classifier that could be a significant time saver for vehicle class counts. Time savings also can occur with the use of computers to store the field data, perform the calculations, and produce reports. If possible, consideration should be given to tying all information to reference points that have been established for all roads in the state under the Roadway Information System, a Mn/DOT roadway storage and retrieval system.

APPENDIX A

ADMIN 1000 (REV. 4/77)

DEPARTMENT Mn/DOT - Transportation Forecasts
Room 807

STATE OF MINNESOTA

Office Memorandum

TO : Richard A. Stehr
Director
Office of Transportation Analysis

DATE: January 10, 1978

FROM : Curt Dahlin, Transportation Forecasts Section
Melvin A. Loesch, Truck Weight Study Unit

PHONE: 6-3153

SUBJECT: SPAR S-251
Summary of Traffic Data Gathered for the
Pilot Program for Evaluating Flexible
Pavements on Local Roads (Investigation 650)

This is a summary of the traffic phase of the above mentioned project based on data collected from Clay, Washington and Wright Counties.

This project was initiated by the Minnesota Local Road Research Board in August 1975 and coordinated by the Physical Research Section of Mn/DOT. The project was started because of insufficient data, available to set realistic spring load restrictions or design bituminous and other road structure improvements.

The report covers the field data collected and the methods used in processing the data. The appendix contains specific data from individual locations in each county.

A study of the information in this report, both specific items and general conclusions, should aid those who have to prepare traffic estimates (particularly estimates of N-18 loadings) on these roads.

TABLE OF CONTENTS

SUMMARY OF FIELD DATA COLLECTED

Approximately 125 miles of county roads were selected for evaluation by the county engineers from the three pilot counties (Clay, Washington and Wright). Locations where data was collected were based primarily on designated routes. The locations were usually at intersections so maximum data could be collected with minimum effort. The traffic data was collected as a starting point in an effort to develop a more solid base for estimating traffic volumes and axle weights on local roads. An extensive amount of data was collected because past experience has shown that there are great variations in the travel patterns on these roads.

There were three types of data collected for this study. They are 1) machine counts of all vehicles, 2) classification of all vehicles by 14 types, and 3) weighing of vehicles. They are detailed as follows:

1) Portable machine counters registering hourly volumes for seven consecutive days in each of the four seasons.

2) Classification by vehicle type for 16 hour period weekday (6 a.m.-10 p.m.) or 24 hours weekday, Saturday and Sunday by the hour and each of the four seasons of the year. The 24 hour counts were necessary to determine nighttime and weekend traffic patterns and to adjust the 16 hour weekday counts to ADT. Nearly all locations are at low volume four legged intersections thereby making it possible for one person to gather data at all four legs at once.

3) Weighing of trucks was conducted for ten hours (7 a.m.-5 p.m.) weekdays in all seasons except winter at approximately ten locations in each county which corresponded to those previously selected sites for machine and vehicle classification counts. An assumption was made that weights were the same during nighttime hours and on weekends. The main concern was to weigh as many trucks as possible to obtain an adequate sample of each vehicle type.

All of this data was collected between the fall of 1975 and the winter of 1977.

METHOD OF PROCESSING DATA

There are two components needed to determine the summation of axle load repetitions (N-18's) on any given road. They are by vehicle type and average day of the year for vehicle type distribution and an average weight represented by an N-18 factor. A majority of the data was gathered in 1976, therefore 1976 will be considered the base year. The three types of data collected are interrelated but will be detailed separately as follows:

1) Machine Counts -

These are seven day hourly counts in each of the four seasons to establish an accurate ADT at these locations. Since hourly counts were taken, corrections could be made for abnormal volumes due to machine malfunctions. The seasonal seven day counts were averaged then the four seasons were averaged also to arrive at an ADT.

2) Vehicle Classification Counts -

Manual counting locations corresponded to the same locations as machine counts. Cars and pickups were grouped as non-commercial vehicles; but two axle dual tire and larger trucks were recorded individually. These raw data were summarized on computer listings illustrating hourly distribution.

To conserve time and expense two locations per county were selected to be counted for a 24 hour period (model stations) for weekdays, Saturday and Sunday. Model station data was first expanded to vehicle type distribution by season. Twenty four hour weekday counts were multiplied by five, Saturday and Sunday counts added and the summary divided by seven to obtain a seasonal distribution. Seasonal distributions were averaged to arrive at a daily distribution. ADT from machine counts were then substituted for calculated ADT figures and the percentage of each vehicle type was applied to the corrected ADT resulting in a more accurate estimate of vehicle type distribution.

Seasonal factors were then established to expand sixteen hour (6 a.m.-10 p.m.) weekday counts to ADT. At each model location the sixteen hour weekday portion is separated from the 24 hour count and compared to the vehicle type distribution for the year. The resulting factors by vehicle type were used to expand sixteen hour counts to ADT.

Model station locations in each county were factored by season and by vehicle type for analysis. After factors were compared on a county and combined basis, we determined the best relationship existed on an individual county level and the best estimate of each set of factors was applied to vehicle class counts.

Individual station factors generally had wide variation due to low volume roads which tend to be less stable then trunk highways.

After applying factors to 16 hour counts, we determined four seasonal answers for each location which were combined and averaged. Machine count ADT was substituted for factored vehicle class ADT resulting in vehicle type distribution for the average day in 1976. All 16 hour counts were adjusted accordingly and are listed by station in the appendix.

3) Weighing of Vehicles -

To determine average weights for 1976 N-18 factors were calculated from data gathered and processed by individual station and vehicle type with summaries by county, season and combined total. Comparisons were made using all possible combinations to evaluate this data. Each factor was weighted based on the number of vehicles weighed. An adequate sample must have 25-30 vehicles of each type weighed which is a major problem with a county road system. Since many of the vehicle types did not meet this criteria, we used N-18 factors from individual locations where weight data was available. One method is to combine data from two or more locations. Sometimes these factors were similar and tended to reinforce one another and for some vehicle types we relied on county averages or a combination of several county averages. This procedure is acceptable because the volume of vehicle types counted parallels the volume of vehicle types weighed. This procedure minimizes the percent of error by using averages.

Actual weight data (N-18 factors and number weighed) are listed by county, season and station in appendix 3.

With the field data processed we have the items necessary to determine a summation of axle load repetitions (N-18's). At this point we may produce reports for 20 year summation of N-18 for new construction, N-18 from time of construction to present or average daily load (ADL) for a given year. The first two items require growth rates. Data supplied to the Physical Research Section was ADL in 1976 for roads previously designated by the county engineers.

This process is briefly described as follows:

All processed data, machine counts, vehicle classification counts and N-18 factors were transcribed to maps of the respective counties. Breaks were established on subject routes by analyzing the ADT and vehicle type distribution. Once segments were defined, 1976 ADT and vehicle type distribution for each link was recorded. After reviewing and selecting N-18 factors we multiply distribution by N-18 factor to obtain ADL. To get design lane value the ADL for each vehicle type is totaled and divided by two.

The annual rate of change was also submitted to use in conjunction with ADL's. These rates of exchange which can be applied to past or future year are 4% for Clay and Wright Counties and 5% for Washington County.

CONCLUSIONS AND RECOMMENDATIONS

Our analysis of data collected for this project revealed some distinctive differences between counties. Clay County is a special case but probably similar to other counties in the Red River Valley and counties like Renville where there is extensive sugar beet production. The predominant vehicle type in Clay County is the 3 axle single unit truck which is used to haul the beets to the processing plant or piling sites at harvest time. There are also a large number of 5 axle semis used to haul beets from piling sites to the plant usually during winter months. This vehicle type distribution is not representative of the major agricultural areas of Minnesota.

Vehicle type distributions in Washington County are closer to Local Roads statewide average distributions than Clay County. This county is also special in that the metropolitan area has a strong influence on its traffic volumes. The average ADT's in Clay and Washington Counties are considerably higher than those in Wright County. Vehicle type distribution is probably similar to that found in other counties located on the fringes of the metro area.

Vehicle type distribution in Wright County is the most typical of that found in other agricultural counties of the state even though it is on the fringe of the metro area. It has the most stable truck traffic patterns of the three counties.

For purposes of comparison Mn/DOT has regularly classified vehicles on local rural roads throughout the state from 1962-1971 at approximately 34 locations nearly every year. Several locations have been counted yearly since that time. This data consistently shows a very close relationship to that from Wright County based on comparison of data by vehicle type. Data gathered for this project reaffirms results of data gathered previously; therefore, we recommend that no more counties be surveyed as a part of this project.

The N-18 factors by county by vehicle type present a mixed picture. Wright County was the most stable in all three seasons and probably most representative of statewide averages. These averages were used as calculated in total. All these analysis were made after excluding station 120 (CSAH 11) in Clay County which carries trunk highway traffic. Some notable observations by vehicle types are as follows:

<u>2 axle dual tire</u>

Clay and Washington County factors are considerably lighter than Wright County.

<u>3 axle single unit</u>

Clay County factors much higher than Wright and Washington. Clay County was considerably high due to sugar beet hauling.

3 axle semis

Volume of trucks weighed was too low to analyze on a county basis. We combined all three counties using the result as a statewide average.

4 axle semis

Clay and Wright Counties were unduly influenced by too few weighed or extremely heavy weights. Washington provided the best sample and was closest to a statewide average.

5 axle semis

No great variation with Clay and Wright Counties being similar and Washington County being slightly lower. The statewide average was used as calculated.

6 axle semis

Due to small number weighed all counties were combined and a statewide average was calculated.

4 & 5 axle truck trailers

Due to small number weighed all counties were combined and a statewide average was calculated.

The recommended application of this material should be used as described below:

One 16 hour vehicle classification count to be taken on any project. The count should be factored by using the table on page 22 in the appendix to determine a vehicle type distribution. If a class count cannot be obtained, a distribution may be determined by examining the counts listed on pages 19-21 of the appendix. This distribution may be further refined by substituting an estimate of the current ADT from any individual county traffic flow map.

To determine N-18 factors, examine factors listed on page 23 in the appendix and select those that most closely fit your vehicle type distribution. Your distribution must be forecast to the design year and averaged with current year distribution to get the midpoint of the period. The midpoint is multiplied by the N-18 factors to get an ADL. This result is multiplied by the number of days in the design period to get the summation of N-18. To obtain design lane value the summation of N-18 is divided by two. This procedure is explained in further detail elsewhere in this report.

CLAY COUNTY TRUCK WEIGHT FACTOR COMPARISON

N18 RATE OF CHANGE SEASONAL AVERAGE

VS STATEWIDE AND INDIVIDUAL TREND LOCATION IN COUNTY

(EXCLUDING STATION 120 CSAH 11)

	Single Unit Trucks						Semis								Truck Trailers			
STUDY PERIOD	2 Axle		3 Axle		4 Axle		3 Axle		4 Axle		5 Axle		6 Axle +		4 Axle		5 Axle	
	# Veh	N18	# Veh	N18	# Veh	N18	# Veh	N18	# Veh	N18	# Veh	N18	# Veh	N18	# Veh	N18	# Veh	N18
SPRING WEIGHTS	111	.117	55	.195	-	-	1	.350	2	.065	20	.464	7	1.324	-	-	3	.055
SUMMER WEIGHTS	121	.198	103	.385	-	-	-	-	2	.147	42	.775	3	.728	-	-	4	.103
FALL WEIGHTS	108	.085	225	1.316	-	-	1	.350	2	.065	20	.558	7	1.322	-	-	3	.055
YEARLY AVERAGE	340	.136	383	.905	-	-	2	.350	6	.093	82	.622	17	1.219	-	-	10	.074
STATEWIDE AVERAGE	367	.232	209	.546	-	-	36	.249	123	.393	929	.796	13	1.152	-	-	64	.513
NET DIFFERENCE - COUNTY		-.096		+.359		-		+.101		-.300		-.174		+.067		-		-.439
STR 172 AVERAGE	20	.438	36	.877	-	-	5	.114	5	.419	34	.663	3	1.107	-	-	8	1.156
NET DIFFERENCE - COUNTY VS YEARLY AVERAGE		-.302		+.028		-		+.135		-.026		-.033		+.112		-		-1.082

Spring and summer N-18 are most alike with the fall being the lightest. This is attributed to the high volume of 3 axle single unit truck hauling sugar beets. The predominant vehicle type is the 3 axle single unit with N-18 of 1.316 which is a full 1.00 higher than spring or summer. Though the N-18's are greater for P.S. 5 vs. statewide average, two of three predominant vehicle types are comparable (2 axle dual and 5 axle semis.)

CLAY COUNTY TRUCK WEIGHT FACTOR COMPARISON

N18 RATE OF CHANGE SEASONAL AVERAGE

VS STATEWIDE AND INDIVIDUAL TREND LOCATION IN COUNTY

INCLUDING STATION 120 (C.S.A.H. 11)

	Single Unit Trucks						Semis								Truck Trailers			
STUDY PERIOD	2 Axle		3 Axle		4 Axle		3 Axle		4 Axle		5 Axle		6 Axle +		4 Axle		5 Axle	
	# Veh	N18	# Veh	N18	# Veh	N18	# Veh	N18	# Veh	N18	# Veh	N18	# Veh	N18	# Veh	N18	# Veh	N18
SPRING WEIGHTS	142	.126	89	.274	1	.488	4	.200	6	.617	115	1.651	13	1.221	2	.573	5	.063
SUMMER WEIGHTS	133	.197	127	.401			3	.976	6	.165	79	.767	3	.728	1	.406	10	.539
FALL WEIGHTS	138	.092	312	1.313	1	.488	2	.239	8	.474	113	1.683	13	1.221	2	.573	5	.063
YEARLY AVERAGE	414	.141	526	.919	2	.488	9	.467	20	.424	307	1.429	29	1.170	5	.540	20	.301
STATEWIDE AVERAGE	367	.232	209	.546	-	-	36	.249	123	.393	929	.796	13	1.152	-	-	64	.513
NET DIFFERENCE - COUNTY		-.091		+.373		-		+.218		+.031		+.633		+.018		-		-.212
ATR 172 AVERAGE	20	.438	36	.877	-	-	5	.114	5	.419	34	.663	3	1.107	-	-	8	1.156
NET DIFFERENCE - COUNTY VS YEARLY AVERAGE		-.297		+.042		-		+.353		+.005		+.766		+.063		-		-.855

As previously stated in this report station 120 (CSAH 11) in Clay County is a special condition due to trunk highway type use. This table was included for comparative purposes. The reason for the high volume and heavy loading factor is this route is used as a bypass from the truck scale at Dilworth and the urban area of Moorhead.

WASHINGTON COUNTY TRUCK WEIGHT FACTOR COMPARISON

N18 RATE OF CHANGE SEASONAL AVERAGE

VS STATEWIDE AND INDIVIDUAL TREND LOCATION IN COUNTY

	Single Unit Trucks						Semis								Truck Trailers			
STUDY PERIOD	2 Axle		3 Axle		4 Axle		3 Axle		4 Axle		5 Axle		6 Axle +		4 Axle		5 Axle	
	# Veh	N18	# Veh	N18	# Veh	N18	# Veh	N18	# Veh	N18	# Veh	N18	# Veh	N18	# Veh	N18	# Veh	N18
SPRING WEIGHTS	154	.196	41	.320	-	-	1	.023	7	.177	1	.069	-	-	1	.018	1	1.358
SUMMER WEIGHTS	106	.111	70	.368	2	2.269	2	.038	2	.062	19	.522	2	.621	2	.072	3	.144
FALL WEIGHTS	177	.157	59	.519	-	-	5	.221	10	.303	35	.407	-	-	2	.077	5	.978
YEARLY AVERAGE	437	.159	170	.409	2	2.269	8	.150	19	.231	55	.441	2	.621	5	.063	9	.782
STATEWIDE AVERAGE	367	.232	209	.546		-	36	.249	123	.393	929	.796	13	1.152	-	-	64	.513
NET DIFFERENCE - COUNTY		-.073		-.137		-		-.099		-.162		-.355		-.531		-		+.211
ATR 354 AVERAGE	54	.165	14	.452		-	3	.064	10	.433	80	.623	-	-	-	-	9	.726
NET DIFFERENCE - COUNTY VS YEARLY AVERAGE		-.006		-.043		-		+.086		-.202		-.182		-		-		+.016

As in Clay County, N-18's for Washington County are lowest for the summer cycle. Three predominant vehicle types (2 axle dual, 3 axle single unit and 5 axle semis) most closely resemble the statewide average. When compared to the individual trend station (ATR 354) only the 5 axle semis are close. Washington County yearly average and ATR 354 most closely match each other in individual N-18 factors.

WRIGHT COUNTY TRUCK WEIGHT FACTOR COMPARISON

N18 RATE OF CHANGE SEASONAL AVERAGE

VS STATEWIDE AND INDIVIDUAL TREND LOCATION IN COUNTY

STUDY PERIOD	Single Unit Trucks						Semis								Truck Trailers			
	2 Axle		3 Axle		4 Axle		3 Axle		4 Axle		5 Axle		6 Axle +		4 Axle		5 Axle	
	# Veh	N18	# Veh	N18	# Veh	N18	# Veh	N18	# Veh	N18	# Veh	N18	# Veh	N18	# Veh	N18	# Veh	N18
SPRING WEIGHTS	173	.210	68	.465	-	-	2	.051	7	3.238	32	.668	2	.858	-	-	3	.607
SUMMER WEIGHTS	152	.225	77	.389	-	-	-	-	11	.408	28	.715	1	.791	3	.233	-	-
FALL WEIGHTS	161	.226	71	.531	-	-	3	.202	5	.328	19	.566	-	-	4	.398	3	.509
YEARLY AVERAGE	486	.220	211	.461	-	-	5	.142	23	1.252	79	.660	3	.835	7	.327	6	.558
STATEWIDE AVERAGE	367	.232	209	.546	-	-	36	.249	123	.393	929	.796	13	1.152	-	-	64	.513
NET DIFFERENCE - COUNTY		-.012		-.085		-		-.107		+.859		-.136		-.317		-		+.045
ATR 358 AVERAGE	76	.322	55	.648	-	-	3	.084	25	.340	170	.684	4	.911	-	-	7	.621
NET DIFFERENCE - COUNTY VS YEARLY AVERAGE.		-.102		-.187		-		+.058		+.912		-.024		-.076		-		-.063

There were no statewide trend locations in Wright County. The one most closely related in ATR 359 at Flying Cloud Airport. These N-18 factors are almost parallel by season and vehicle type.

TRUCK WEIGHT FACTOR COMPARISON

N18 RATE OF CHANGE 3 COUNTY

SEASONAL AVERAGE VS STATEWIDE

STUDY PERIOD	Single Unit Trucks						Semis								Truck Trailers			
	2 Axle		3 Axle		4 Axle		3 Axle		4 Axle		5 Axle		6 Axle +		4 Axle		5 Axle	
	# Veh	N18	# Veh	N18	# Veh	N18	# Veh	N18	# Veh	N18	# Veh	N18	# Veh	N18	# Veh	N18	# Veh	N18
SPRING WEIGHTS	438	.182	164	.338	-	-	4	.119	16	1.503	53	.580	10	1.216	1	.018	8	.466
SUMMER WEIGHTS	379	.185	245	.392	2	2.269	2	.039	15	.327	89	.701	6	.703	6	.208	7	.095
FALL WEIGHTS	446	.164	356	1.027	-	-	9	.228	17	.330	74	.463	8	1.311	6	.292	11	.597
YEARLY AVERAGE	1263	.177	765	.676	2	2.269	15	.174	48	.720	216	.550	24	1.119	13	.232	26	.4[illegible]
STATEWIDE AVERAGE	367	.232	209	.546	-	-	36	.249	123	.393	929	.796	13	1.152	-	-	64	.513
NET DIFFERENCE - COUNTY		-.057		+.130		-		-.075		+ .327		-.206		.033		-		-.091

At this point the pilot study counties could be placed in three separate categories.

1. Washington County urban commuter with some recreational.
2. Clay County is basically agricultural but because of the heavy sugar beet production could be termed industrial agricultural.
3. Wright County fits most closely to an average agricultural or farm to market type county because of the small seasonal variations and the increase in the fall harvest season of 2 axle dual and 3 axle single units.

Our conclusion is if weighing is to be conducted in the counties for N-18's, it should be done in the late summer or early fall for best average factors.

ALTERNATE METHODS OF GATHERING DATA

The fall cycle for weighing trucks in Clay County was cancelled. The county engineer indicated that we would not get any cooperation from the sugar beet haulers which could prove to be dangerous if we attempted to stop and weigh vehicles.

Through the cooperation of the agricultural manager at the Crystal sugar plant we were able to obtain sample weights of loaded front and tandem axle groups and their computer listing of tonnage carried for each truck load of beets. Percent relationships of the front axle to the total vehicle weight of the samples were calculated and arranged into three weight groups. The samples in each weight group were averaged and this percent applied to load carried from Crystal sugar computer run. This weight is added to the average empty weights table from the states Truck Weight Study Program. The same procedure is used to determine the tandem group as well as the front axle.

A map of the county was submitted to Crystal sugar indicating our research locations. Their agricultural manager in turn marked his computer run of sugar beet loads with our station numbers as determined from the most likely route the hauler would take to the plant. From this data records were created and added to duplicated spring weights which most closely match fall averages. All data was submitted to the truck equivalency program and N-18 factors were determined for the fall cycle for Clay County.

This same procedure could be used in any part of the state with cooperation from a grain elevator for example.

Washington County attempted to classify vehicles using a portable machine classifier which proved to be unsatisfactory. Based on an analysis of data collected in the fall of 1975 and again in the fall of 1976, the machine classification method was unable to properly categorize vehicles causing a critical % HCADT error.

Weekday, Saturday and Sunday machine counts were taken simultaneously with manual vehicle classification counts in the fall of '76. These comparisons substantiated the departments claims that there are too many discrepancies using this method.

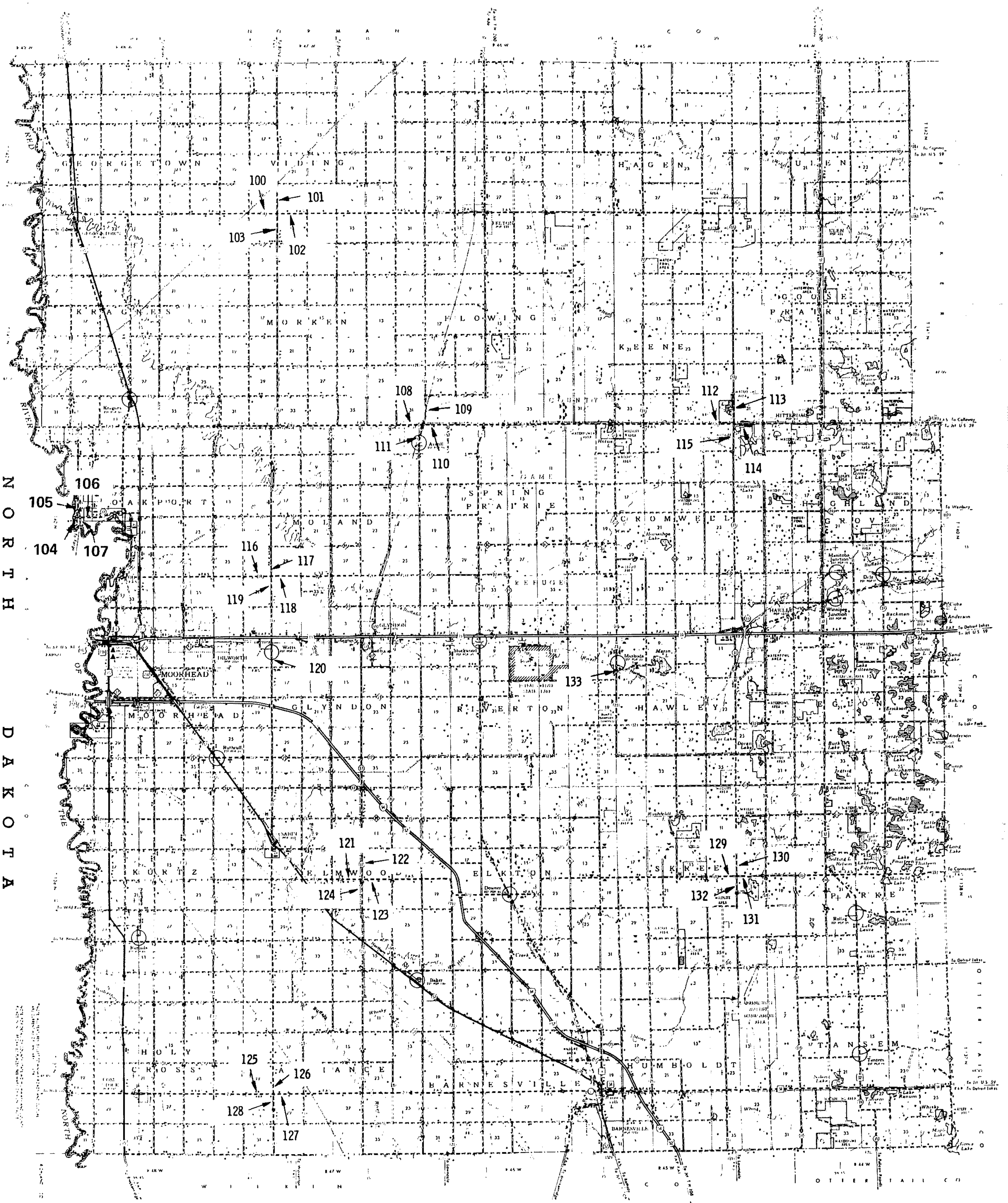
Several examples where auto- and two axle single unit categories for the machine method are added together show they would be nearly equal to the manual counts. In some cases multi-unit vehicles would have to be converted to two autos each to equal the manual method of classification.

Several reasons for the machine vehicle classifiers inability to accurately accumulate data are:

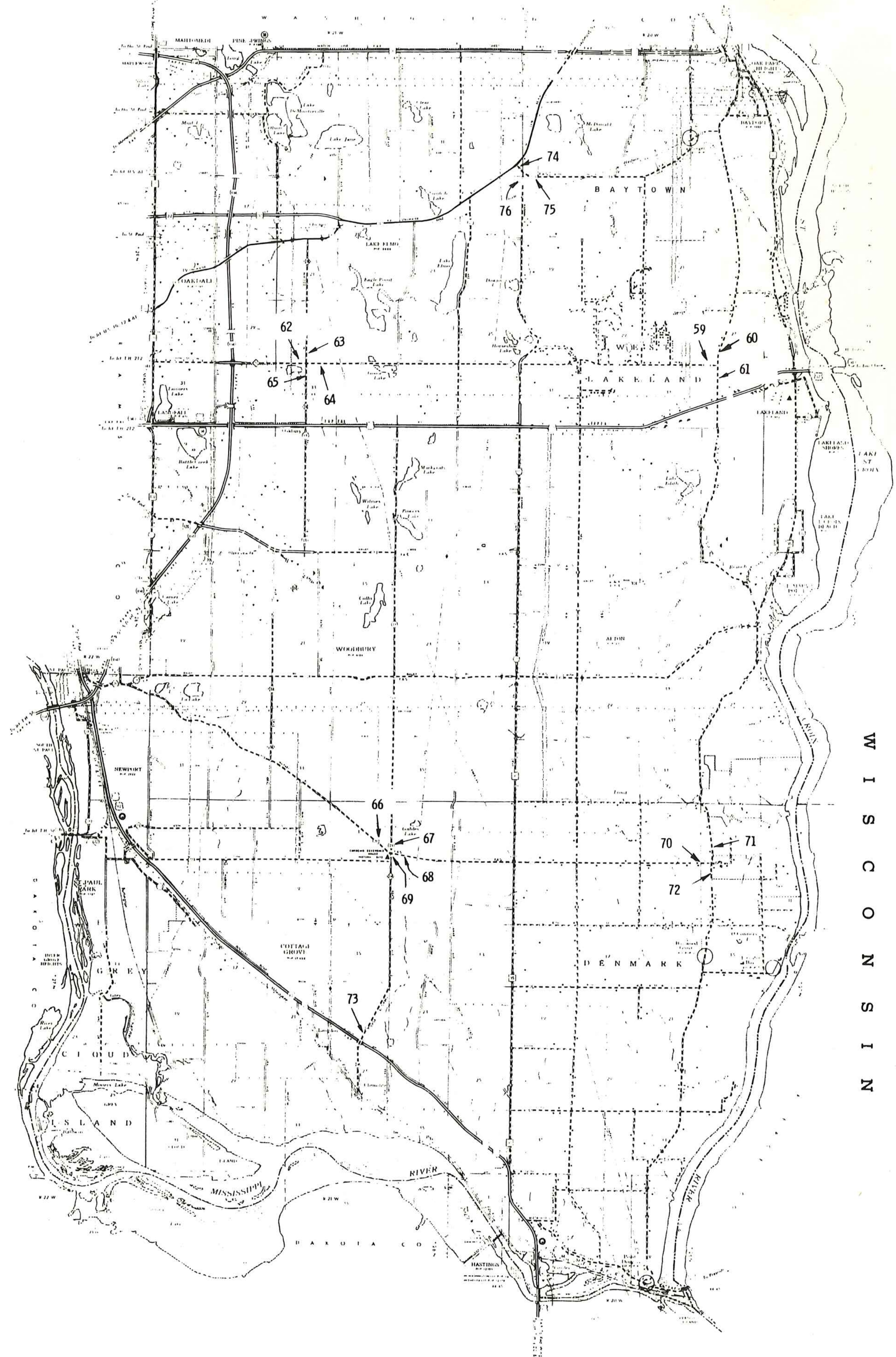
1. Slower speeds when counter is placed too close to an intersection.

2. Two vehicles passing over the tubes at about the same time can be registered as one or as one multi-axle vehicle.

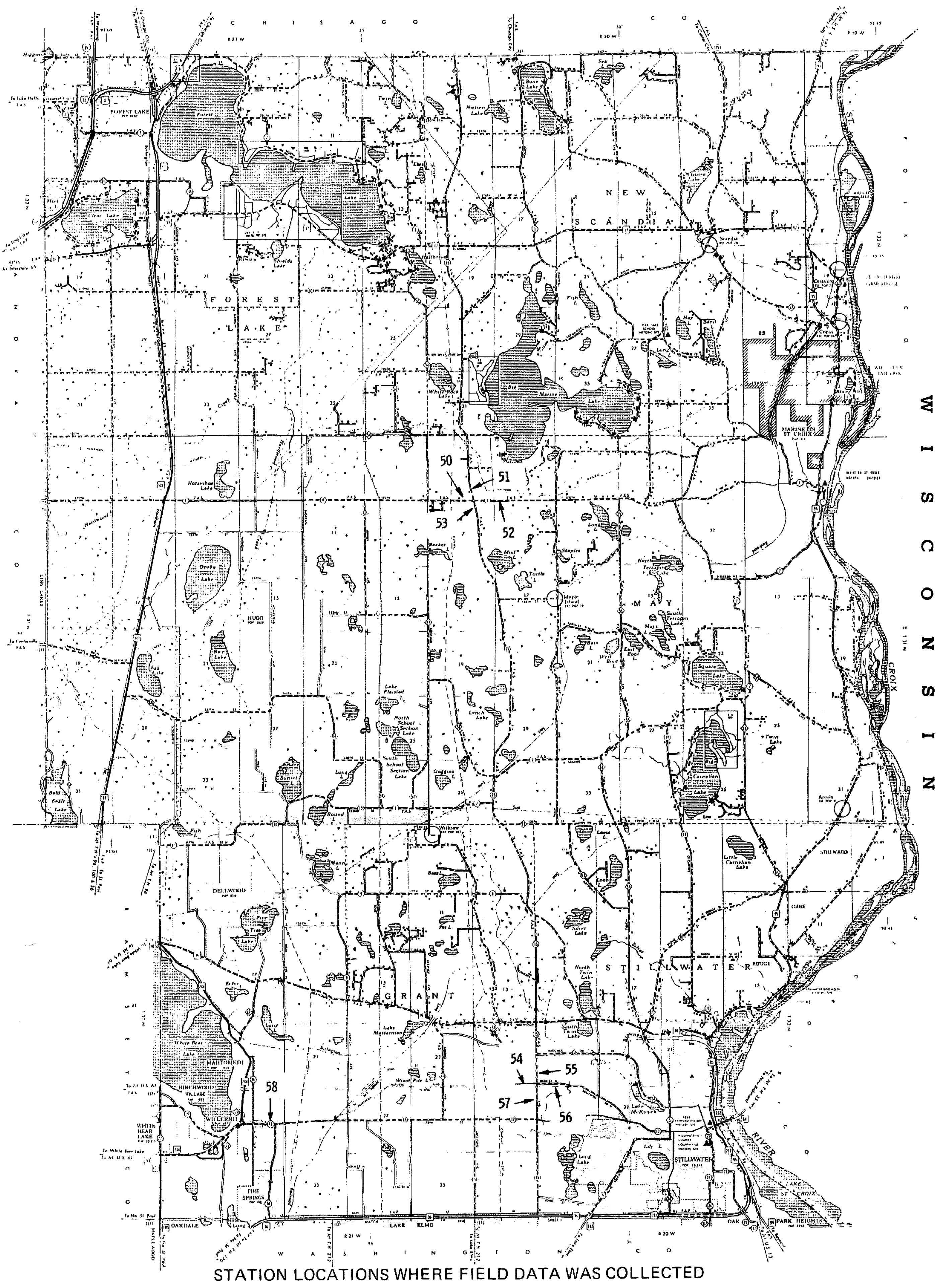
APPENDIX



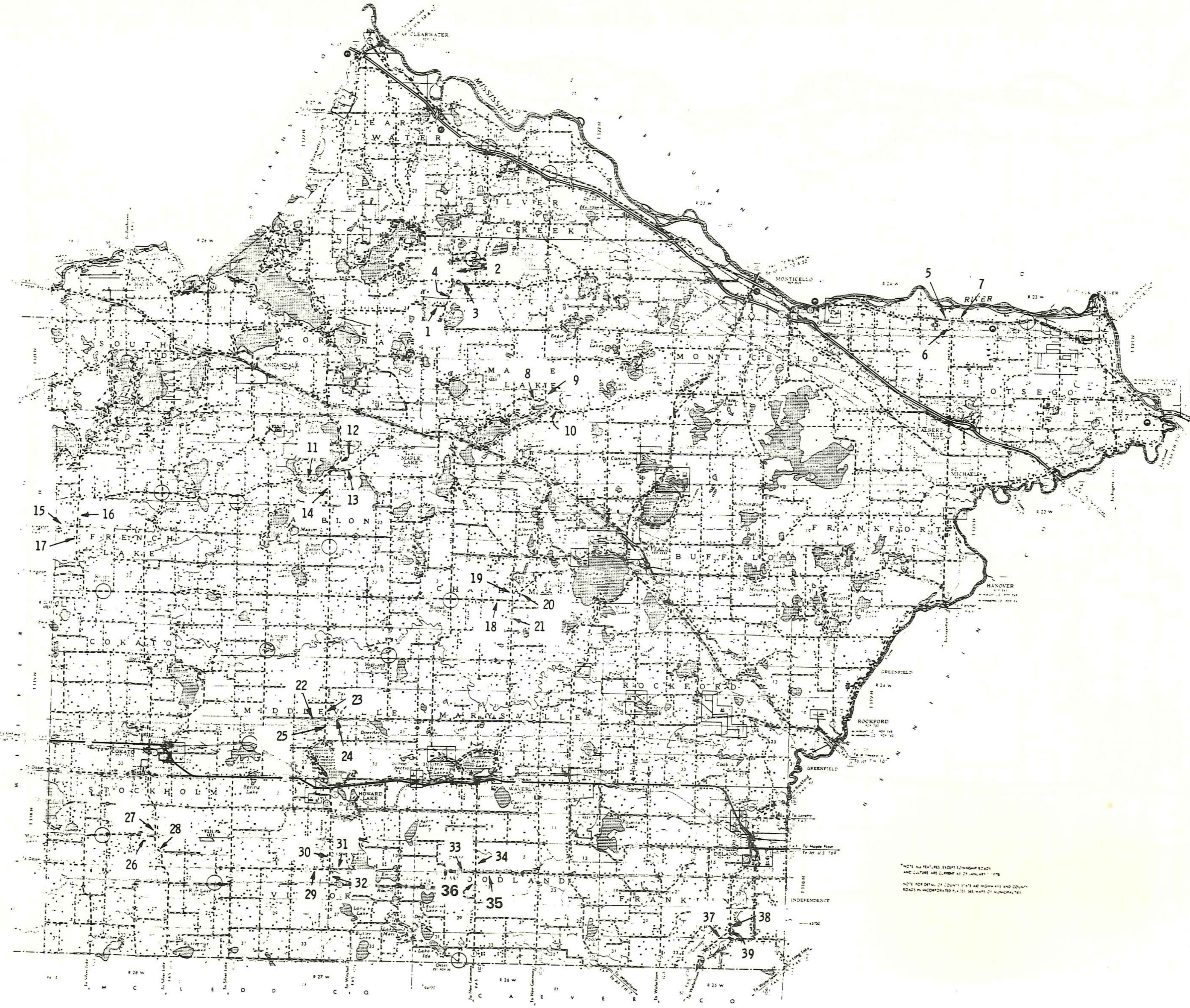
STATION LOCATIONS WHERE FIELD DATA WAS COLLECTED
CLAY COUNTY



STATION LOCATIONS WHERE FIELD DATA WAS COLLECTED
WASHINGTON COUNTY



STATION LOCATIONS WHERE FIELD DATA WAS COLLECTED
WASHINGTON COUNTY



STATION LOCATIONS WHERE FIELD DATA WAS COLLECTED
WRIGHT COUNTY

Calculated Vehicle Type Distributions for Clay County, 1976

Station #	Cars & Pickups	2 axle 6 tire	3 & 4 axle single unit	3 axle semi	4 axle semi	5 or more axle semi	buses	Truck trailers	Total ADT	Total HCADT
100	129	9	15	-	-	2	1	-	156	27
101	76	2	56	-	-	-	1	-	135	59
102	184	5	78	-	-	1	1	-	269	85
103	239	6	26	-	-	1	2	-	274	35
104	2450	70	140	1	4	84	3	9	2761	311
105	1573	37	72	-	2	7	3	4	1698	125
106	2200	41	65	1	2	72	3	4	2388	188
107	2423	15	3	-	-	1	2	1	2445	22
108	535	25	35	-	2	26	2	13	638	103
109	817	49	110	2	9	276	4	46	1313	496
110	471	16	25	-	1	15	2	23	553	82
111	680	34	93	1	8	273	3	55	1147	467
112	315	18	6	-	-	9	2	-	350	35
113	187	10	9	-	-	3	2	-	211	24
114	450	31	7	-	1	7	2	-	498	48
115	302	13	10	-	1	1	1	-	328	26
116	289	9	206	-	-	22	2	1	529	240
117	477	15	34	-	1	7	5	-	539	62
118	245	7	77	-	-	18	2	-	349	104
119	397	10	117	-	1	10	2	1	538	141
120	2909	125	370	5	11	496	2	62	3980	1071
121	123	9	15	-	-	2	-	1	150	27
122	94	4	22	-	-	2	2	-	124	30
123	163	14	16	-	-	3	1	1	218	35
124	14	2	1	-	-	1	-	-	18	4
125	181	8	15	-	-	11	3	-	218	37
126	207	11	38	-	1	17	-	-	274	67
127	135	6	18	-	-	9	3	1	172	37
128	218	12	46	-	1	13	-	-	290	72
129	746	12	10	-	1	9	1	9	788	42
130	203	7	10	-	1	2	1	1	225	22
131	733	11	10	-	-	10	1	9	774	41
132	190	6	10	-	-	1	1	1	209	19
133	181	16	23	-	-	66	1	-	287	106
Total*	17,647	540	1418	5	36	981	59	180	20,866	3219
%	84.6	2.6	6.8	-	0.2	4.7	0.3	0.8	100.0	15.4

* Without Station 120 (CSAH 11) which carries Trunk Highway traffic between TH 10 & I-94

Calculated Vehicle Type Distributions for Washington County, 1976

Station #	Cars & Pickups	2 axle 6 tire	3 & 4 axle single unit	3 axle semi	4 axle semi	5 or more axle semi	buses	Truck trailers	Total ADT	Total HCADT
50	982	16	25	-	-	3	7	1	1034	52
51	1264	15	21	1	1	6	6	1	1315	51
52	915	9	5	-	-	3	5	1	938	23
53	1161	27	19	1	1	5	2	2	1218	57
54	64	2	4	-	-	-	-	-	70	6
55	3392	76	42	1	4	12	11	4	3542	150
56	728	17	6	-	1	1	7	-	760	32
57	3309	70	34	1	4	12	11	3	3444	135
58	2550	57	36	-	1	9	31	2	2686	136
59	485	14	4	-	-	4	11	-	518	33
60	802	20	21	-	1	19	13	1	877	75
61	950	28	27	-	1	24	6	1	1037	87
62	1814	19	4	-	-	4	11	1	1853	39
63	656	8	3	-	-	-	10	-	677	21
64	1649	18	5	-	-	4	12	1	1689	40
65	565	8	2	-	-	-	6	1	582	17
66	1085	30	9	1	3	4	14	1	1147	62
67	990	28	28	1	4	4	15	2	1072	82
68	1331	41	15	1	5	2	34	3	1432	101
69	1383	46	34	1	4	4	27	2	1501	118
70	672	12	8	-	-	1	19	-	712	40
71	481	12	8	-	-	1	10	-	512	31
72	381	9	7	-	-	2	4	-	403	22
73	620	20	8	-	1	4	6	1	660	40
74	2111	58	64	1	2	6	15	3	2260	149
75	1042	29	13	1	-	2	4	1	1092	50
76	1549	45	53	1	2	4	14	2	1670	121
Total	32,931	734	505	11	35	140	311	34	34,701	1770
%	94.9	2.1	1.5	-	0.1	0.4	0.9	0.1	100.0	5.1

Calculated Vehicle Type Distributions for Wright County, 1976

Station #	Cars & Pickups	2 axle 6 tire	3 & 4 axle single unit	3 axle semi	4 axle semi	5 or more axle semi	buses	Truck trailers	Total ADT	Total HCADT
1	349	10	5	-	-	-	4	1	369	20
2	627	27	9	-	1	4	3	1	672	45
3	258	7	3	-	-	-	3	-	271	13
4	719	29	10	-	1	4	3	1	767	48
5	760	12	10	-	-	15	8	-	825	45
6	465	10	8	-	-	10	5	1	499	34
7	689	16	9	-	-	2	4	2	722	33
8	728	31	19	-	1	2	1	1	783	55
9	350	9	4	-	-	-	2	1	366	16
10	824	33	21	-	-	2	1	2	883	59
11	363	13	5	-	-	1	1	-	383	20
12	420	17	8	-	-	1	3	1	450	30
13	559	18	9	-	-	1	3	-	590	31
14	578	25	11	-	-	3	3	1	621	43
15	324	10	3	-	-	-	5	-	342	18
16	375	12	14	-	-	1	3	4	409	34
17	309	12	9	-	-	2	1	3	336	27
18	568	16	3	-	-	-	2	-	589	21
19	88	7	3	-	-	-	2	-	100	12
20	821	23	5	-	-	1	2	-	852	31
21	306	18	6	-	-	-	2	-	332	26
22	45	1	1	-	-	-	-	-	47	2
23	595	23	12	-	-	2	4	1	637	42
24	183	9	5	-	-	1	1	-	199	16
25	608	26	10	-	-	2	4	1	651	43
26	441	14	26	-	-	1	1	1	484	43
27	846	29	4	-	-	2	4	2	887	41
28	565	20	24	-	-	2	3	1	615	50
29	344	15	5	-	-	-	3	-	367	23
30	1193	56	27	-	3	24	7	3	1313	120
31	27	2	1	-	-	-	-	-	30	3
32	1066	53	29	-	3	25	6	3	1185	119
33	262	8	7	-	-	-	3	-	280	18
34	529	28	24	-	1	2	3	2	589	60
35	422	17	5	-	1	1	2	-	448	26
36	565	33	27	-	1	2	5	1	634	69
37	476	17	2	-	1	4	1	2	503	27
38	606	21	3	-	1	4	2	2	639	33
39	296	7	2	-	-	-	1	-	306	10
Total	19,569	734	388	-	14	121	111	38	20,975	1406
%	93.3	3.5	1.8	-	0.1	0.6	0.5	0.2	100.0	6.7

Factors to Expand 16 Hour Weekday

Vehicle Classification Counts to ADT

	Winter	Spring	Summer	Fall
Cars & pickups	1.32	1.23	1.00	1.10
2 axle 6 tire	1.26	.84	.92	.72
3 & 4 axle single unit	1.43	.95	.74	.68
3 axle semi	1.00	.69	1.25	.92
4 axle semi	.98	1.14	.88	.88
5 or more axle semi	1.36	1.21	.95	.54
Buses	.73	.55	1.11	.78
Truck-trailers	1.16	.88	1.02	.61

Recommended N-18 Factors

	Clay	Wright	Washington	Statewide (Other than Red River Valley)
2 axle 6 tire	.14	.22	.16	.21
3 axle single unit	.91	.46	.41	.45
3 axle semi	.15	.15	.15	.15
4 axle semi	.30	.38	.23	.30
5 axle semi	.62	.66	.44	.59
6 axle semi	1.02	1.02	1.02	1.02
4 axle truck-trailer	.23	.23	.23	.23
5 axle truck-trailer	.45	.45	.45	.45

ADMIN 1000

STATE OF MINNESOTA

Office Memorandum

DEPARTMENT Mn/DOT - Transportation Forecasts
Room 813

TO : Erland Lukanen
Research Project Engineer
Research & Standards Section

DATE: December 11, 1978

FROM : Kenneth C. Kopitzke, Director
Transportation Forecasts Section
Kenneth Kopitzke

PHONE: 6-6759

SUBJECT: SPAR S-251A
Summary of Traffic Data Gathered in Municipalities for the Pilot Program for Evaluating Flexible Pavements on Local Roads (Investigation 650)

This is a summary of the traffic phase of the above mentioned projected based on data collected in six municipalities in the Twin City Metropolitan area. The locations of the projects are as follows:

City	Street	Location
St. Louis Park	Texas Ave.	TH 12 to Cedar Lake Rd.
White Bear Lake	McKnight	Cedar to County Rd. F
Blaine	Polk	99th Ave. N.E. to Quincy Ave.
Fridley	61st Ave. N.E.	Moore Lake Dr. to University Ave.
Brooklyn Center	Humboldt	65th Ave. to 69th Ave.
Brooklyn Center	Humboldt	69th Ave. to 73rd Ave.
South St. Paul	21st Ave.	Southview to Wentworth

The field data collected in this area (municipal streets) of the project was not nearly as extensive as that collected in the county phase of the project. There were two types of data collected for this municipal phase. They are 1) machine counts of all vehicles, and 2) classification of all vehicles by type. There was no weight data gathered.

The machine counts were taken for a period of seven consecutive days. Some locations were counted in the summer of 1976 and others in the fall. All locations were counted only once. They were all adjusted to ADT by using factors which are based on data recorded at automatic traffic recorders.

The vehicle class counts were taken for one 16 hour period (6 a.m.-10 p.m.) on a weekday. Most of them were taken in October or November 1976 with one of them taken in February 1977. These counts were adjusted to ADT by using factors developed for the Metropolitan area. There was no vehicle class count taken for the site in Blaine.

The N-18 factors were estimated after examining weight data collected at other locations in the Metropolitan area.

The annual rate of change to apply to these values is 3% per year. This was based on an examination of the historical counts on these streets.

The following page summarizes the data collected and the average daily load (N-18 summation) for 1976.

Calculated Vehicle Type Distributions and Average Daily Load (N-18) for 1976

	Texas Ave.	McKnight	Polk[1]	61st Ave. N.E.	Humboldt 65th to 69th	Humboldt 69th to 73rd	21st Ave.
Cars & Pickups	3399	2859	2721	4171	6517	3813	2242
2 axle 6 tire	197	12	48	33	745	454	14
3 & 4 axle single unit	4	1	14	4	18	13	--
3 axle semi	--	--	--	2	3	1	--
4 axle semi	--	1	2	2	6	3	--
5 or more axle semi	--	--	4	--	10	1	--
buses	65	60	11	48	68	45	59
truck trailers	--	2	--	--	3	--	--
Total ADT	3665	2935	2800	4260	7370	4330	2315
Total HCADT	266	76	79	89	853	517	73
Average Daily Load (N-18)	85	36	20	18	237	144	34

1. This is an estimate. No vehicle class count was taken here.

APPENDIX B

INVESTIGATION 650
Pilot Program for Evaluation of the Structural Adequacy of Flexible Pavement for Counties and Municipalities

Clay County

CSAH No.	Termini	Length Mi.	Pavement Thickness, (in.) Planned	Pavement Thickness, (in.) Measured	Base Thickness, (in.) Planned	Base Thickness, (in.) Measured	Soil Type Class. or S.F.	R-Value	AADT	HCADT	Daily N-18	N18 x 10^{-3} Last Surfacing to Present	N18 x 10^{-3} Benkelman Beam	Spring Restriction T	Measured Tonnage T	Benkelman Beam Deflections x 10^3 $\bar{X}$	Std. Dev.	Range	PSR	SR	Date of Construction / Date Resurfaced	Estimated Life in Years By N18	To PSR of 2.5
1	North end Br. No. 90817 to CSAH No. 26	3.29	3-1/2	4-3/4	10	3-3/3	CL	10	1698	125	14.5	15	56	5	5.9	80.5	15.2	58-125	3.3	3.9	1962-1973	7	3
9	T.H. 10 to CSAH No. 18	1.99	7	7-1/4	8	9-1/2	CL	10	156	26	6.5	7	413	—	13.4	31.4	5.1	23-40	3.0	4.0	1973 -	53	1
10	Jct. Old T.H. 52 to Co. Rd. 69	2.99	1-1/2	2-1/8	10	11	C	10	184	31	10.3	41	60	7	7.1	42.2	24.4	30-124	3.1	4.0	1965 -	5	7
10	Jct. Co. Rd. 69 to I-94	4.36	3	3-3/4	13	15-3/4	CL	10	218	35	10.3	26	530	7	16.4	28.6	4.4	24-38	3.1	4.0	1967 -	47	4
10	I-94 to Jct. T.H. 9										11.3	29	368		13.9	33.3	8.3	20-51				37	
10	Jct. T.H. 9 (Downer) to pt. 2-1/2 m E.	2.50	1-1/2	2-1/2	12	17-1/8	SL	20	788	42	11.3	32	129	5	10.0	46.1	14.3	17-84	3.2	3.7	1968 -	17	6
10	Pt. 2-1/2 m E of Downer to CSAH No. 31	5.61	1-1/2	2		15-1/2	SL	20	788	42	11.3	38	143	5	10.5	54.0	13.0	36-93	3.2	3.7	1966 -	18	8
10	CSAH No. 31 to T.H. No. 32	3.30	1-1/2	2-1/2	11	13-1/2	SL-CL	10-20	774	41	10.4	30	48	5	6.4	78.7	21.9	36-132	3.2	3.7	1968 -	5	6
10	T.H. 32 to East Co. Line	3.81	1-1/2	2-3/4	8	11	CL-SL-S	10-20	774	41	6.0	24	27	5	4.9	90.9	34.1	34-148	2.5	3.8	1963 -	1	0
11	South Co. Line to CSAH No. 2	2.34	1-1/2	2-5/8	12	14-1/2	CL	10	290	72	17.4	58	51	5	6.6	79.8	29.4	71-135	2.6	2.7	1966	0	1
11	CSAH No. 2 to CSAH No. 4	4.00	3-1/2	4-3/4	10	13-1/4	CL	10	274	67	17.1	24	154	5	8.6	46.9	12.9	32-72	3.0	3.5	1960-1973	16	2
11	CSAH No. 4 to CSAH No. 8	1.00	2-1/2	3	8	10-7/8	CL	10	274	67	17.1	24	65	5	6.3	80.2	32.8	35-152	3.0	3.5	1957-1973	6	2
11	CSAH No. 8 to CSAH No. 52	3.20	1-1/2	3-7/8	8	12-3/8	CL-SL	10-20	274	67	17.1	88	31	5	4.5	80.2	32.8	35-152	3.0	3.5	1957 -	0	8
11	CSAH No. 52 to I-94	2.30	3-1/2	3-7/8	11	12-3/8	CL-SiL	10-20	623	106	17.9	25	129	7	8.6	51.2	18.5	26-96	3.8	3.9	1965 - 1973	13	13
11	I-94 to T.H. 10	2.10	4	4-3/8	15	18-3/4	CL	10	3980	1071	504	1003	330	—	8.8	44.0	8.7	26-62	3.1	3.0	1965 - 1971	0	3
11	T.H. 10 to CSAH No. 18	2.00	3	3-3/8	8	9-1/2	CL	10	538	141	37.6	106	35	5	4.1	91.7	22.0	75-129	3.0	3.8	1957 - 1968	0	4
11	CSAH No. 18 to CSAH No. 26	5.10	1-1/2	2	6	8-1/8	CL	10	539	62	15.6	52		5	4.5	114.7	31.1	66-213	—	—	—	—	—
11	CSAH 26 to NW Corn. Sec. 21, T14N, R47W	3.00	3	3	8	12-3/8	C, SiL, CL	10-20	274	35	11.4	32	40	5	5.0	96.1	31.0	60-245	3.2		1957-1968	2	6
11	NW Corn, Sec. 21, T14N, R47W to CSAH No. 34	4.00	3	2-3/4	10	13-7/8	C	8	274	35	11.4	50	15	5	3.7	121.8	44.2	75-245	3.2		1961	0	11
11	CSAH No. 34 to North Co. Line	5.01	5-1/2	5	3	7-5/8	C	8	135	59	27.0	58	51	5	4.7	83.5	17.7	58-147	3.0		1971	0	3
12	CSAH 52 to CSAH 11 (Nr. Ruthruff)	1.94		8-1/4	0	0	CL	10	163	28	2.8	9		—	13.4	30.4	9.7	11-46	2.4				0
17	CSAH No. 10 to T.H. 10	8.42	3	3-3/4	13	13-1/8	SiL, SL CL, C	8-20	124	30	7.7	17	129	7	9.3	40.9	14.4	24-70	3.8		1970	24	23
18	CSAH No. 3 to T.H. 75	0.80	3	6-1/2	8	8	C	8	529	240	82.3	139	188	5	5.9	47.9	4.2	43-53	2.9	3.7	1964-1971	2	2
18	T.H. 75 to Co. Rd. 90	2.50	5	6-1/8	9	12	C CL	8-10	529	240	82.3	274	133	5	5.3	55.7	11.1	50-71	2.9	3.7	1965	0	3
18	Co. Rd. 90 to CSAH No. 11	2.00	5	5-5/8	9	11	CL	10	529	240	82.3	254	109	5	5.3	60.4	10.7	50-73	2.9	3.7	1966	0	3
18	CSAH No. 11 to CSAH No. 19	3.70	5	5-7/8	9	12-1/4	CL	10	349	104	40.0	113	149	5	7.6	52.4	9.2	37-71	2.9	3.7	1967	2	3
19	Jct. T.H. 10 to Jct. Co. Rd. 84	0.96	1-1/2	3	10	14	CL SiL	10-20	400	68	40.0	133	83	5	7.0	46.1	9.5	35-63	3.1	3.4	1965	0	6
19	Jct. Co. Rd. 84 to CSAH No. 18	1.00	2	3	12	12-3/4	CL	10	400	68	40.0	103	167	5	8.0	64.3	22.5	46-93	3.1	3.4	1968	4	4
22	Red River to CSAH No. 1	0.20	1-1/2	5-3/4	9	10-3/8	C	8	2761	311	53.2	177	34	5	3.9	69.7	18.7	56-91	3.0	3.6	1965	0	5
22	CSAH No. 1 to Co. Rd. 96	1.60	4	4-1/2	10	12-3/4	C	8	2388	188	35.0	37	37	5	4.1	86.4	28.6	58-159	3.0	3.6	1959-1967 1973	0	1
23	CSAH No. 12 to T.H. 10	2.99	10	10	0	0	SL	20	287	106	34.0	24	1065	—	15.0	18.0	6.5	12-30	3.3	4.0	1975	37	2

INVESTIGATION 650

Pilot Program for Evaluation of the Structural Adequacy of Flexible Pavement for Counties and Municipalities

Clay County

CSAH No.	Termini	Length Mi.	Pavement Thickness, (In.) Planned	Pavement Thickness, (In.) Measured	Base Thickness, (In.) Planned	Base Thickness, (In.) Measured	Soil Type Class. or S.F.	R-Value	AADT	HCADT	Daily N-18	N18 x 10^{-3} Last Surfacing to Present	N18 x 10^{-3} Benkelman Beam	Spring Restriction T	Measured Tonnage T	Benkelman Beam Deflections x 10^3 $\bar{X}$	Std. Dev.	Range	PSR	SR	Date of Construction / Date Resurfaced	Estimated Life in Years By N18	To PSR of 2.5
26	CSAH No. 1 to T.H. 75	2.00	3-1/2	3-7/8	12	11-1/2	C	8	1053	179	14.5	20	48	5	5.5	82.0	20.6	66-105	2.9	3.7	1963 1973	5	1
26	T.H. 75 to CSAH No. 11	4.30	1-1/2	2-5/8	12	12-1/2	C	8	641	109	10.9	44	33	5	5.4	98.8	22.1	42-149	2.9	3.7	1963	0	4
26	CSAH No. 11 to T.H. 9	6.70	1-1/2	2-3/8	12	14-7/8	C SiL	8-20	638	103	15.9	57	51	5	6.6	60.9	25.6	27-140	3.1	3.9	1965	0	7
26	T.H. 9 to CSAH No. 33	8.30	3-1/2	4-3/4	8	12-7/8	CL	10	451	59	5.6	8	143	5	9.8	53.8	16.0	21-94	3.1	3.9	1965 1973	33	2
31	South Co. Line to T.H. 34	2.19	2	2-5/8	8	12-1/8	CL SL	10-20	121	21	5.2	12	47	5	6.8	77.7	16.3	57-100	2.9	4.0	1971	15	2
31	T.H. 34 to CSAH No. 6	4.50	1-1/2	2	8	11-3/8	CL	10	209	19	5.2	24	38	5	6.1	88.5	21.2	49-130	2.7	2.5	1960	6	2
31	CSAH No. 6 to CSAH No. 10	3.00	1-1/2	1-3/4	10	12-1/2	CL SL	10-20	209	19	5.2	22	52	5	7.1	69.9	18.5	49-107	2.7	2.5	1962	13	2
31	CSAH No. 10 to T.H. 10	8.01	5	5-1/2	6	10-5/8	CL SL	10-20	225	22	7.8	18	188	7	110	41.5	18.4	20-94	3.0	4.0	1972	31	2
33	T.H. 10 to Reno St. in Hawley	0.30	2	—	12	—	—	—	328	26	3.6	10	160	5	11.8	43	12.1	22-57	2.7	3.6	1970	44	1
33	Reno St. in Hawley to 735' North of County Road 114	2.20	1-1/2	2-1/2	8	10	CL	10	328	26	3.6	19	20	5	4.6	105.6	29.0	51-146	2.7	3.6	1957	1	3
33	735' No. of Co. Rd. 114 to CSAH 26	4.60	1-1/2	2-3/8	8	10-3/8	CL	10	328	26	3.6	17	35	5	5.9	94.7	20.4	51-146	2.7	3.6	1959	11	2
34	T.H. 75 to CSAH No. 5	2.79	1-1/2	3-3/8	8	10-3/8	C	8	156	27	11.0	34	30	5	4.4	93.0	14.4	79-120	3.3	3.8	1957	0	18
34	CSAH No. 5 to CSAH No. 11	4.00	3-1/4	3-7/8	10	11-3/8	C	8	156	27	11.0	19	38	5	4.9	109.4	16.8	75-174	3.3	3.8	1959 1967 1972	4	4
36	West End Bridge No. 6646 to T.H. 75	1.08	9	8-5/8	0	0	C	8	107	18	4.3	9	233	7	10.3	41.9	4.7	35-48	2.8	4.0	1971	49	1
Co. Rd. 96	CSAH No. 18 to CSAH No. 22	2.36	—	7-1/4	—	0	C	8	1698	125	35.0	—	—	5	3.6	86.8	15.6	60-125	2.6	3.2	—	—	—
	TOTAL	143.84																					

INVESTIGATION 650

Pilot Program for Evaluation of the Structural Adequacy of Flexible Pavement for Counties and Municipalities

Washington County

CSAH No.	Termini	Length Mi.	Pavement Thickness, (in.) Planned	Pavement Thickness, (in.) Measured	Base Thickness, (in.) Planned	Base Thickness, (in.) Measured	Soil Type Class. or S.F.	R-Value	AADT	HCADT	Daily N-18	N18 x 10^{-3} Last Surfacing to Present	N18 x 10^{-3} Benkelman Beam	Spring Restriction T	Measured Tonnage T	Benkelman Beam Deflections x 10^{3} $\bar{X}$	Std. Dev.	Range	PSR	SR	Date of Construction / Date Resurfaced	Estimated Life in Years By N18	To PSR of 2.5
1	T.H. 97 to North County Line	3.20	2-1/2	3-3/4	10	11-3/4	LS SL FSL	20-70	707	28	3.3	8	389	7	15.4	30.4	6.1	21-44	2.6	3.9	1968	66	1
4	T.H. 61 to 2.3 miles East	2.30	4-1/2	5-1/2	15	15	FS LFS	20-70	1034	52	6.4	5	704	7	20.2	27.3	3.6	18-34	2.5	3.5	1974	65	0
4	2.3 miles E. of T.H. 61 to CSAH 15	3.30	3	2-5/8	7	12-3/8	LS SL FSL	20-70	1034	52	6.4	24	256	7	12.7	37.6	7.9	23-51	2.5	3.5	1963	40	0
4	CSAH No. 15 to Co. Road 81	1.30	5	2-3/8	9	10	CL SL FSL	20-70	938	23	3.2	12	567	7	21.1	26.8	3.9	22-33	2.5	3.5	1963	76	0
4	County Rd. 81 to County Rd. 55	1.00	1-1/2	2-1/2	6	12-5/8	FSL SiL LFS	20-70	938	23	3.2	14	389	7	17.8	30.9	5.0	22-38	2.5	3.5	1961	67	0
4	Co. Road 55 to CSAH No. 3	0.40	1-1/2	2-3/8	6	11	FSL SiL LFS	20-70	938	23	3.2	14	497	7	18.3	30.0	3.6	27-34	2.5	3.5	1961	73	0
4	CSAH 3 to 0.3 mile East of West limits of Marine	1.70	1-1/2	2-5/8	6	10-3/8	FSL SiL SL	20-70	494	12	1.2	5	530	7	17.7	28.6	4.4	22-34	2.5	3.5	1961	99	0
4	0.3 mile East of West limits of Marine to T.H. 95	1.70	1-1/2	4	6	12-1/2	FSL MS SCL	12-20	494	12	1.2	7	180	7	10.8	36.2	10.3	22-60	2.5	3.5	1950	71	0
5	T.H. 212 to Owens St. in Stillwater	1.40	4-1/2	6-3/8	12	15	FSL SiCL SL S&G	20-75	2398	156	20.0	62	823	9	16.7	23.0	5.7	16-33	2.6	3.8	1966	42	1
7	CSAH No. 18 to CSAH No. 15	1.10	4-1/2	5-1/2	15	8-3/8	FSL LFS SL	20	758	32	3.8	9	704	7	20.2	25.4	3.6	18-29	2.6	4.0	1969	77	0
8	CSAH No. 10 to CSAH No. 7	0.70	3-1/2	3	0	0	FSL LFS SL	20	758	32	3.8	9	223	—	11.9	42.0	4.7	38-49	2.2	3.5	1969	50	0
12	T.H. 244 to McGregor Avenue	0.30	4-1/2	5	18	14	LFS LS	20	2686	136	18.1	51	894	9	20.8	22.6	3.2	20-26	2.2	3.5	1967	46	0
12	McGregor Ave. to 1/2 mi. E. Mahtomedi	1.00	4-1/2	5-1/8	15	8-1/8	LFS FSL	20	2686	136	18.1	25	704	9	18.6	24.2	5.3	18-29	2.2	3.5	1972	42	0
12	1/2 mi. E. of Mahtomedi to CSAH 37 (South Junction)	3.40	1-1/2	5	0	0	LS SL LFS	20	1841	114	14.5	77	90	6	6.5	59.5	16.6	41-108	2.4	3.5	1955	2	0
12	No. Jct. CSAH 37 & 12 to West limits of Stillwater	2.00	1-1/2	5-1/2	0	0	SL FSL VFSL	20	760	32	4.0	21	112	6	8.0	51.2	13.8	38-79	2.4	3.5	1955	32	0
12	W. limits of Stillwater to CSAH 5	0.70	1-1/2	3-5/8	0	0	SL SiL VFSL	20	760	32	4.0	29	180	6	10.8	41.7	22.0	22-86	2.4	3.5	1940	42	0
13	CSAH No. 6 to T.H. 212	0.40	3-1/2	3-7/8	3	18	LFS FSL	20	606	20	2.3	10	466	5	16.7	29.0	5.7	22-35	2.3	3.8	1961	80	0
13	T.H. 212 to County Rd. 68	2.00	3-1/2	3-1/2	3	8	SL LFS VFSL	20	930	45	5.5	23	389	5	15.4	33.6	5.0	22-40	2.3	3.8	1961	54	0
13	County Road 68 to T.H. 36	2.70	1-1/2	3-3/8	0	0	LFS SiL SL	20-30	596	19	2.2	13	102	—	9.0	59.6	23.1	43-125	2.3	3.8	1950	43	0

Pilot Program for Evaluation of the Structural Adequacy of Flexible Pavement for Counties and Municipalities

Washington County

CSAH No.	Termini	Length Mi.	Pavement Thickness, (in.) Planned	Pavement Thickness, (in.) Measured	Base Thickness, (in.) Planned	Base Thickness, (in.) Measured	Soil Type Class. or S.F.	R-Value	AADT	HCADT	Daily N-18	N18 x 10^3 Last Surfacing to Present	N18 x 10^3 Benkelman Beam	Spring Restriction T	Measured Tonnage T	Benkelman Beam Deflections x 10^3 $\bar{X}$	Std. Dev.	Range	PSR	SR	Date of Construction	Date Resurfaced	Estimated Life in Years By N18	To PSR of 2.5
13B	T.H. 12 to Co. Rd. 70 (Former Cty Rd. 80)	2.00	2	4-3/8	7	8	FSLLS&G	30	582	17	1.9	7	180	5	10.8	44.2	7.0	38-59	2.3	3.7	1964		61	0
13B	Co. Rd. 70 to 1.0 miles North	1.00	2	4-1/2	8	6	FSL, SIL, SL	20-30	677	21	2.5	9	180	5	10.8	46.3	7.7	38-59	2.3	3.7	1964		55	0
13B	1.0 mi. N of Co. Rd. 70 to T.H. 212	1.00	—	4	—	7	VFSL FSL SiL, SiCL	10-30	677	21	2.5	—	—	5	—	38.4	7.1	27-49	2.3	3.7	—		—	0
14	T.H. 212 to CSAH No. 21	3.60	7	7-3/4	4	5	FSL, SiL SL	20-70	1092	50	6.0	—	—	9	—	—	—	—	2.8	3.9	1946	1969	—	2
14	CSAH No. 21 to T.H. 95	0.70	2-1/2	4-7/8	6	8	LS & G	70	1132	60	7.5	—	—	9	—	—	—	—	2.8	3.9	1958	—	—	4
15	T.H. 95 to 10th Street South	3.00	5	7-1/8	5	12	SiL, FS	20-70	1193	65	8.1	—	—	7	—	—	—	—	2.7	3.9	1953	1969	—	1
15	10th Street South to T.H. 12	1.00	5	6-1/4	5	7	SiL, FS FG	20-70	1193	65	8.1	—	—	7	—	—	—	—	2.7	3.9	1951	1969	—	1
15	T.H. 12 to 0.3 miles North	0.30	7	7	5	6	SL, FSL	70	1578	93	11.9	—	—	7	—	—	—	—	2.7	3.9	1970		—	1
15	0.3 mi. No. of T.H. 12 to 0.8 mi. North of T.H. 12	0.50	6	6-1/4	5	6	SiL, SL FSL	20-70	1578	93	11.9	—	—	7	—	—	—	—	2.7	3.9	1951	1964	—	2
15	0.8 mi. No. of T.H. 12 to East Limits of Lake Elmo	5.00	7	7-1/4	5	12	SiL, LFS, LS	20-30	1670	121	16.5	—	—	7	—	—	—	—	2.7	3.9	1970		—	1
17	T.H. 12 to 1.0 mile North	1.00	3-1/2	5-1/2	9	16	SL LS FSL	20-30	2084	132	16.9	68	368	9	12.7	33.4	6.3	26-45	2.6	3.5	1962		28	1
17	1.0 mi. N of T.H. 12 to 2.0 mi. No.	1.00	3-1/2	6	9	9	SiL FS VFSL	20-70	2125	133	17.3	69	438	9	16.2	29.4	5.2	23-36	2.6	3.5	1962		31	1
17	2.0 mi. N. of T.H. 12 to T.H. 212	2.30	4	3-3/4	12	9	LFS FSL LVFS	20-70	2125	135	17.3	66	438	9	16.2	25.9	7.7	18-42	2.6	3.5	1963		31	1
17	T.H. 212 to T.H. 36	2.40	7	3-3/4	0	0	LFS S SL	30-75	798	35	4.2	10	567	7	16.9	26.9	8.3	16-57	2.6	3.5	1950	1969	70	0
18	CSAH 20 to 0.18 mile East	0.20	7	5-1/4	17	18	SL	30	1102	58	7.2	—	—	9	—	—	—	—	2.4	3.6	1966		—	0
18	0.18 mile East of CSAH 20 to 0.7 mile East of Newport	0.50	1-1/2	5-1/8	9	9	LS & G	50	1102	58	7.2	—	—	7	—	—	—	—	2.4	3.6	1958		—	0
18	0.7 mile East of Newport to 1.04 miles East of Newport	0.30	4-1/2	5-1/2	11	10	SL	30	1102	58	7.2	—	—	7	—	—	—	—	2.4	3.6	1974		—	0
18	1.04 mi. E. of Newport to CSAH 9	3.40	1-1/2	5-1/2	9	6	LS FSL LS & G	30-70	1102	58	7.2	—	—	7	—	—	—	—	2.4	3.6	1958		—	0
18	CSAH 19 to T.H. 95	2.00	4-1/2	5-1/2	15	18	LS SL LS & G	30-70	970	48	5.9	6	1116	7	25.4	20.4	2.7	17-23	2.4	3.6	1973		79	0
19	T.H. 61 to CSAH 22	3.00	4-1/2	4-3/8	5	8	S LFS LS & G	50-75	1072	82	7.1	—	—	7	—	—	—	—	2.7	3.8	1968		—	1
19	CSAH 22 to 1.0 mi. S. of CSAH 18	2.00	4-1/2	4	5	8	LS S S&G	50-75	1501	118	12.8	—	—	7	—	—	—	—	2.7	3.8	1968		—	1

INVESTIGATION 650
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Washington County

CSAH No.	Termini	Length Mi.	Pavement Thickness, (In.) Planned	Pavement Thickness, (In.) Measured	Base Thickness, (In.) Planned	Base Thickness, (In.) Measured	Soil Type Class. or S.F.	R-Value	AADT	HCADT	Daily N-18	$N18 \times 10^{-3}$ Last Surfacing to Present	$N18 \times 10^{-3}$ Benkel-man Beam	Spring Restriction T	Measured Tonnage T	Benkelman Beam Deflections $\times 10^3$ $\bar{X}$	Std. Dev.	Range	PSR	SR	Date of Construction / Date Resurfaced	Estimated Life in Years By N18	To PSR of 2.5
19	1.0 miles South of CSAH 18 to CSAH 16	3.00	3	4	5	9	LFS, FSL LS & G	50-70	1618	97	12.3	—	—	7	—	—	—	—	2.7	3.8	1966	—	2
19	CSAH 16 to T.H. 12	2.20	3-1/2	5-1/2	4	14	FSL, SiL SL	20-30	1527	90	11.4	—	—	7	—	—	—	—	2.7	3.8	1953 1969	—	1
20	CSAH 19 to Oakgreen Avenue	2.00	3-1/2	3-3/8	9	9	Sil, LS L	20-70	1432	101	11.6	44	1169	5	23.5	18.3	3.9	14-23	2.3	3.2	1054 1963	63	0
20	Oakgreen Avenue to CSAH 21	3.20	1-1/2	4-1/4	7	8	Sil, FSL LFS	20-70	712	40	4.9	24	1169	5	25.4	20.7	5.4	14-37	2.3	3.2	1958	83	0
21	T.H. 10 to 0.5 mile North	0.50	1-1/2	3-1/4	6	9	SiL	20	667	25	2.9	17	180	5	10.8	42.3	15.8	20-54	2.2	3.3	1952	50	0
21	0.5 mile North of T.H. 10 to 1.5 mile North of T.H. 10	1.00	1-1/2	3-1/2	6	8	FS, FSL, SiL	20-70	667	25	2.9	15	54	5	6.2	65.1	34.2	14-138	2.2	3.3	1957	23	0
21	1.5 mi. N. T.H. 10 to Co. Rd. 76	1.60	1-1/2	3-1/2	6	9	SiL, F SL	20-70	667	25	2.9	13	180	5	10.8	42.2	19.4	14-89	2.2	3.3	1959	51	0
21	Co. Rd. 76 to 1.0 mile North	1.00	1-1/2	3-1/4	6	8	S, SL, FSL	70	403	22	2.9	15	47	5	5.8	53.9	29.6	26-122	2.2	3.3	1956	20	0
21	1.0 mi. N. of Co. Rd. 76 to CSAH 20	1.10	1-1/2	5	6	9	SiL, FS, LMS	20-70	403	22	2.9	14	49	5	6.0	62.2	29.6	26-111	2.2	3.9	1958	21	0
22	T.H. 61 to East limits of St. Paul Park	0.50	1-1/2	5	8	8	S, CL, LS & G	12-15	1446	84	10.6	44	368	7	13.8	31.0	5.4	24-39	2.6	3.9	1961	37	0
22	East limits of St. Paul Park to 1.7 miles East	1.70	4	6-3/8	3	7	SiL, LS	20-30	1446	84	10.6	24	368	7	13.8	24.8	8.2	15-44	2.6	3.9	1942 1969	39	0
22	1.7 miles East of St. Paul Park to CSAH 19	2.10	4	5-1/2	3	7	SiL, SiCL, SL	20-30	1147	62	9.3	21	368	7	12.5	26.3	8.4	15-42	2.6	3.9	1955 1969	41	0
67	CSAH 14 to 57th Street North	0.50	—	6-1/2	—	16	SL, FSL	30	1203	66	8.2	—	—	5	12.7	23.8	10.4	17-39	2.5	3.9	—	—	—
67	57th Street North to T.H. 36	1.00	7	3-3/4	17	9	SiCL, SL	12-30	1203	66	8.2	9	180	9	10.8	46.3	7.6	30-59	2.5	3.9	1973	30	0
16	F.A.I. 494 to Afton Road	1.60	8	8-3/4	14	15	SiL, SiCL, LS	12-30	1578	94	11.9	16	1776	9	26.1	17.7	2.6	13-19	2.7	4.0	1970	82	1
16	Afton Road to CSAH 19	1.80	8	5-7/8	14	4	LS, SL	30	1092	57	7.1	24	974	9	19.8	21.9	3.5	17-30	2.7	4.0	1970	58	1
15	T.H. 36 to T.H. 96	3.00	—	3-7/8	—	8	FSL, LFS	30	2700	61	20.9				12.7	26.8	5.1	16-33	2.8	3.9	—	—	—
15	T.H. 96 to Co. Road 58	3.90	—	7	—	6	FSL, LS, LS & G	20-30	2100	41	13.0				13.4	31.2	7.4	16-45	2.8	3.9	—	—	—
15	Co. Rd. 58 to CSAH 4	4.40	—	6-1/2	—	6	CL, SL, FSL	10-30	1100	29	8.3				12.2	37.9	21.0	16-45	2.8	3.9	—	—	—
15	CSAH 4 to T.H. 97	4.00	—	7-3/8	-	8	SL, LFS, FSL	10-30	1050	28	8.1				14.4	31.0	6.1	20-45	2.8	3.9	—	—	—
21	T.H. 12 to CSAH 14	4.40	—	6-3/4	—	8	SiL, FSL FS, VFSL	20-70	1025	50	16.6				6.8	49.3	13.8	27-73	2.5	3.9	—	—	—

INVESTIGATION 650
Pilot Program for Evaluation of the Structural Adequacy of Flexible Pavement for Counties and Municipalities

Wright County

CSAH No.	Termini	Length Mi.	Pavement Thickness, (in.) Planned	Pavement Thickness, (in.) Measured	Base Thickness, (in.) Planned	Base Thickness, (in.) Measured	Soil Type Class. or S.F.	R-Value	AADT	HCADT	Daily N-18	N18 x 10^{-3} Last Surfacing to Present	N18 x 10^{-3} Benkel-man Beam	Spring Restriction T	Measured Tonnage T	Benkelman Beam Deflections x 10^3 $\bar{X}$	Std. Dev.	Range	PSR	SR	Date of Construction / Date Resurfaced	Estimated Life in Years By N18	Estimated Life in Years To PSR of 2.5
2	CSAH No. 35 to 1.6 mi. No.	1.6	1-1/2	2	6	6-1/2	FS FSL FLS CL CLT	20-70	336	27	4.7	20	35	5	6.5	73.4	26.8	39-126			·63	7.8	
2	1.6 mi. No. of CSAH No. 35 to CSAH No. 37 East	0.9	1-1/2	2	6	6-1/2	CL CLT FSL	10-20	409	34	5.2	22	34	5	6	92.8	19.1	72-129			1963	5.7	
3	So. County Line to CSAH No. 30 East [1]	2.5	1-1/2	4-5/8	NG	5-1/4	C CLT CL	10	615	50	3.3	15	23	5	4.2	111	26	46-144			1938 NA	6.3	
3	East CSAH No. 30 -- West CSAH No. 30 [2]	1.8	1-1/2	3	8	10	C CL CLT	10	615	50	3.3	15	23	5	8.4	55	17	25-95			1938 1959	6.3	
3	West CSAH No. 30 to South Village Limits of Cokato	2.2	1-1/2	2-3/8	8	8-3/8	C CL CLT	10	887	41	4.4	17	96	5	9.4	56	21	15-98			1949 1960	30.3	
3	So. Village Limits of Cokato to .25 miles North	0.25	1-1/2	2	8	11	CL CLT	10	887	41	4.4	30	72	5	9.7	29	20	16-52			1959	22.1	
3	0.25 North of Cokato limits to T.H. No. 12	0.75	1-1/2	2	12	14	CLT SiCL	10-20	887	41	4.4	19	120	5	12	38.3	20.7	21-65			1959	34.3	
6	South County Line to South Limits of Howard Lake	5.5	1-1/2	11	9	9	C CL CLT	10	1313	120	25.4	43	269	9	12	31.0	8.0	18-48			1973	17.4	
6	South Limits of Howard Lake to T.H. No. 12	0.69	3	7-3/8	11	18-1/2	CL CLT FS	10-70	1313	120	25.4	122	466	9	11	34.9	5.5	28-46			1960	23.2	
6	T.H. 12 to North Limits of Howard Lake	0.31	3	3-3/8	14	14-1/2	C CL CLT	10	651	43	6.3	19	567	5	9.7	41.5	14.2	29-60			1968	60	
6	North Limits of Howard Lake to CSAH No. 35	6.5	3-1/2	5-3/4	6	3	C CL CLT	10	637	42	6.3	9	49	5	6	65.2	19.7	34-114			1952 1974	13.5	
6	CSAH No. 35 to CSAH No. 37	4.1	3-1/2	7-1/4	6	3	C CL CLT	10	621	43	6.5	7	37	5	5.1	65.2	19.7	34-114			1948 1975	10.7	
6	CSAH No. 37 to T.H. No. 55	2.6	3-1/2	5-1/4	6	5	SLT LS CL CLT	10-20	450	30	4.9	5	106	5	7.6	68.8	25.8	35-149			1941 1975	30	
6	T.H. No. 55 to T.H. No. 24	2.6	3-1/2	2-1/2	6	7	S CLT LS SL	10-70	628	43	7.3	8	106	4	7.8	68.8	25.8	35-149			1957 1975	23	
8	Carver County Line to CSAH No. 30	3.1	1-1/2	3	9-1/2	9	SF 100 C CL CLT	10	634	69	6.3	11	163	7	7.5	56.6	7.2	43-63			1973	33	
8	CSAH No. 30 to T.H. 12	3.0	2	3	11	11-1/2	S.F. 100 C CL CLT	10	589	60	12.8	51	60	7	8.4	65.6	17.9	42-140			1964	1.9	
8	T.H. No. 55 to CSAH No. 37	0.25	NA	11	NA	0	S.F. 100 C CL CLT	10	767	48	9.3	52	418	7 (2 test points)	7.35	36.8	8.2	24-46			1955	43	
8	CSAH No. 37 to Co. Rd. 106	2.7	3	5-1/2	11	10	S.F. 100 C CL CLT	10	767	48	9.3	37	503	7	7.0	33.8	16.4	8 - 75			1964	48	
8	Co. Rd. 106 to 2.9 mi. so. of CSAH 75	4.6	3	3-3/4	11	11-1/2	S.F. 50 C CL CLT	10	767	48	6.0	19	595	7	7.4	31.3	16.0	6-70			1968	62	
8	1 mile north of Silver Creek to 0.4 mile south T.H. 152	2.4	2	3-3/8	3	6	S.F. 50 SL CL LS & G	10-20	672	45	6.0	21	227	7	9.0	22.5	11.0	10-46			1966	80	

[1] Possible overlay

[2] Curves rebuilt and subcuts excavated in 1959

Wright County

CSAH No.	Termini	Length Mi.	Pavement Thickness, (in.) Planned	Pavement Thickness, (in.) Measured	Base Thickness, (in.) Planned	Base Thickness, (in.) Measured	Soil Type Class. or S.F.	R-Value	AADT	HCADT	Daily N-18	N18 x 10^{-3} Last Surfacing to Present	N18 x 10^{-3} Benkelman Beam	Spring Restriction T	Measured Tonnage T	Benkelman Beam Deflections x 10^3 $\bar{X}$	Std. Dev.	Range	PSR	SR	Date of Construction / Date Resurfaced	Estimated Life in Years By N18	To PSR of 2.5
8	.4 mile south of T.H. 152 to T.H. 152	0.4	NA	3-3/8	NA	36	S.F. 50 SL CL LS & G	10-20	672	45	6.0	21	1,227	7	9.7	23.5	9.3	14-36			NA	80	
9	Elm Ave. in Waverly to County Road No. 107	2.1	NA	4-7/8	NA	0	S.F. 100 C CL CLT	10	332	26	5.3	34	24	5	4	93.1	37.7	37-169			1938 NA	0	
9	County Road No. 107 to CSAH No. 35	3.9	2-1/2	3-3/8	8	11	S.F. 100 SL CLT LFS	10-30	332	26	5.3	27	47	5	6.6	68.8	24.9	27-120			1958	8.6	
16	So. County Line to T.H. No. 12	4.2	3	5-3/4	11	14	S.F. 100 CL CLT	10	503	27	3.9	13	244	9	10.6	25.9	11.6	8-65			1967	51	
17	Bridge Ave. in Delano to North boundary of Delano	0.7	3	3	5	15	S.F. 100 SL CL	12-30	863	45	12.3	61	608	5	14.6	29.0	9.3	12-44			1959	45	
17	No. Delano limits to East County line	1.1	2	3	NA	10	S.F. 100 CL SL	12-30	771	43	5.1	29	188	5	9.7	40.4	15.2	16-53			1933 1955	38	
19	Crow River in Hanover to South St. Michael Village Limits	3.2	3	3-1/2	10	12	S.F. 100 C CL CLT	10	825	45	12.4	13	88	7	6.9	59.2	12.9	42-82			1967	19	
19	So. limits of St. Michael to .19 mile north of T.H. 241	0.9	3	4	11	10	S.F. 100 C CLT SL	10-30	760	45	13.3	18	348	7	12.9	39.5	2.5	36-42			1962	33	
19	.2 mile north T.H. 241 to North St. Michael Village limits	0.5	3	4-3/4	14	6	S.F. 100 CL LS & G	10-20	499	34	13.3	18	160	7	7.5	50.5	14.9	30-72			1974	20	
19	No. village limits of St. Michael to CSAH No. 35	.25	3	4-3/4	14	6	S.F. 100		499	34	13.3	59	313	7	13	38.2	6.3	22-42			1974	23.8	
19	CSAH No. 35 to CSAH No. 39	4.5	3	4	11	19	S.F. 100 CLT VFSL	10-20	499	35	13.3	44	102	7	9.3	41	16	22-95			1973	9.9	
35	CSAH No. 2 to CSAH No. 3	2.7	3-1/2	6-1/2	NG	5	S.F. 100 CL CLT SL	10-20	422	41	5.2	24	46	5	6.7	75.7	16.0	52-107			1951 1973	9.6	
35	CSAH No. 3 to CSAH No. 4	2.5	3	3-1/4	5	9-1/2	S.F. 100 CL FSL LS	10-30	308	38	5.2	32	46	5	8.4	69.3	19.7	45-118			1941 1961	6.4 yr.	
35	CSAH No. 4 to CSAH No. 6	3.5	1-1/2	2-3/8	8	10	S.F. 100 CL SiCL LS	10-20	413	40	5.2	9	47	5	6.9	80	15	37-108			1961 1963	15	
35	CSAH No. 6 to CSAH No. 9	6.0	1-1/2	2-3/8	8	10	S.F. 100 CL SiCL SL	10-30	589	21	3.2	15	40	5	6.1	77	19	31-115			1961	15	
35	CSAH No. 9 south to CSAH No. 9 west	1.8	1-1/2	3	8	8	S.F. 100 CL CLT LFS	10-70	852	31	5.7	29	45	5	6	80	25	45-102			1958	6.6	
35	CSAH No. 9 west to west Buffalo City limits[1]	2.7	NA	3-1/8	NA	10	S.F. 100 CL CLT S	10-75	852	31	9.2	41	530	5	5.2	72	23	24-122			1927 ?	49	
35	West Buffalo City Limits to 1st Ave. N.W.[1]	0.2	2	2-1/2	NA	6	S.F. 100 CL CLT	10	1324	48	9.2	31	213	5	9.9	54.5	—	50-59			1928 ?	29	
35	1st Ave. N.W. to T.H. No. 25 in Buffalo	0.2	3	2-1/2	11	6	S.F. 100 CL CLT	10	1324	48	9.2	31	40	5	16	34	—	33 to 35			1962	2.6	
37	CSAH No. 8 to CSAH No. 11	3.7	3	3-1/2	NA	4	S.F. 100 C CL CLT	10	783	55	9.5	19	26	5	4	92.1	29.7	35-141			1940 1972	1.8	

[1]Old TH 55, no records

INVESTIGATION 650
Pilot Program for Evaluation of the Structural Adequacy of Flexible Pavement for Counties and Municipalities

Wright County

CSAH No.	Termini	Length Mi.	Pavement Thickness, (in.) Planned	Pavement Thickness, (in.) Measured	Base Thickness, (in.) Planned	Base Thickness, (in.) Measured	Soil Type Class. or S.F.	R-Value	AADT	HCADT	Daily N-18	N18 x 10^-3 Last Surfacing to Present	N18 x 10^-3 Benkel-man Beam	Spring Restriction T	Measured Tonnage T	Benkelman Beam Deflections x 10^3 $\bar{X}$	Std. Dev.	Range	PSR	SR	Date of Construction / Date Resurfaced	Estimated Life in Years By N18	To PSR of 2.5
37	CSAH No. 11 to County Rd. No. 131	4.6	1-1/2	2-3/4	8	9-1/2	S.F. 100 C CL CLT	10	883	59	9.5	52	90	5	8.8	51.2	17.8	16-93			1956 1960	9.3	
37	County Rd. No. 131 to CSAH No. 15	2.1	1-1/2	4-1/2	6	6	S.F. 50 SL LS	20-76	868	45	4.4	17	149	5	10.4	39.2	17.1	18-82			1965	37	
37	CSAH No. 15 to County Road No. 119	4.0	1-1/2	2-5/8	8	7	S.F. 100 C CL SCL	10-20	349	39	4.4	20	67	5	7.4	70.0	16.7	37-104			1961 1964	19.6	
37	County Rd. No. 119 to 1 mile west of CSAH No. 19	2.6	1-1/2	2-1/2	8	8	S.F. 100 S LS CLT	12-75	344	39	4.4	16	59	5	6.5	68.3	25.4	28-144			1963 1966	18.6	
37	1 mile west of CSAH No. 19 to CSAH No. 19 (Albertville)	1.0	1-1/2	5-5/8	8	3	S.F. 100 CL CLT	10	340	39	4.4	16	59	5	7.1	68.3	25.4	28-144			1966	18.6	
37	West County Line to CSAH No. 2	0.7	1-1/2	5	8	5	S.F. 100 CL CLT C	10	164	34	2.8	12	72	5	7.9	76.1	13.8	55-86			1957 1962	30.2	
37	CSAH No. 2 to CSAH No. 3	2.7	1-1/2	3	8	7	S.F. 100 C CL CLT	10	227	36	4.7	21	47	5	7.8	72.8	16.1	51-106			1957 1962	12	
37	CSAH No. 3 to CSAH No. 5	3.6	3	2-3/8	NA	7	S.F. 100 C CL CLT	10	382	40	4.7	5	41	5	7.1	74.7	20.4	36-123			1953 1975	15.6	
37	CSAH No. 5 to CSAH No. 6	2.2	1-1/2	2-1/4	8	6	S.F. 100 SL SCL CLT	10-30	383	20	4.7	21	54	5	6.2	75.8	19.7	48-129			1960 1962	14.5	
37	CSAH No. 6 to T.H. No. 55	3.0	4	2-3/8	NA	8	S.F. 100 C CL CLT	10	590	31	5.4	12	37	5	5.4	81.8	24.2	32-134			1950 1971	10.2	
39	CSAH No. 75 to 2.8 miles east	2.8	2-1/2	3-3/4	0	0	S.F. 50 SL SL & G	70	825	45	10.1	14	62	5	8.3	45.9	12.9	25-72			1941 1974	10.7	
39	2.8 miles east of CSAH No. 75 to CSAH No. 19	2.5	2-1/2	5-1/4	0	0	S.F. 50 CLT LS & G	10-70	825	45	10.1	14	62	5	6.8	56.1	21.0	23-120			1953 1975	10.7	
39	CSAH No. 19 to CSAH No. 37	3.6	3	3-1/4	8	13	S.F. 50 CLT SL	20-70	722	33	6.2	16	567	7	15.6	24.5	9.3	13-47			1970	60.5	
39	CSAH No. 37 to County Road No. 130	1.3	3	3-1/8	8	8	S.F. 50 SL LS&G	20-70	1573	49	13.6	35	438	7	13.4	25.4	8.5	16-36			1970	37	
39	County Road No. 130 to TH 101	0.3	3	3-3/8	11	4	S.F. 50 LFS SL	70	1573	49	13.6	35	438	7	13.4	25.4	8.5	16-36			1968 1970	37	
	Total	132.6																					

INVESTIGATION 650

Pilot Program for Evaluation of the Structural Adequacy of Flexible Pavement for Counties and Municipalities

METRO AREA

Termini	Length Mi.	Pavement Thickness, (in.) Planned	Pavement Thickness, (in.) Measured	Base Thickness, (in.) Planned	Base Thickness, (in.) Measured	Soil Type Class. or S.F.	R-Value	AADT	HCADT	Daily N-18	N18 x 10^-3 Last Surfacing to Present	N18 x 10^-3 Benkel-man Beam	Spring Restriction T	Measured Tonnage T	Benkelman Beam Deflections x 10^3 $\bar{X}$	Std. Dev.	Range	PSR	SR	Date of Construction / Date Resurfaced	Estimated Life in Years By N18	To PSR of 2.5
Texas Ave. (St. Louis Park) Cedar Lake Rd. to So. Service Dr. Hwy. No. 12[1]		7-1/2 - 12-1/2		5 - 10-1/2			30	3665	266	85			0	10.0	27.9	6.7	16-51	2.9	3.9	1974		5
61st. Ave. (MSA No. 302) (Fridley) Baker St. to T.H. No. 65		2-1/2		6				4260	89	18			9	14.6	28.0	7.0	21-40	2.5	3.0	1966		0
61st. Ave. Carol Drive to Baker Str.		3		3				4260	89	18			9	21.7	23.6	2.6	21-27	2.5	3.0	1971		0
61st. Ave. University Ave. to Carol Dr[2]		1-1/2		4				4260	89	18			9	17.2	29.3	6.1	18-49	2.5	3.0	1964		0
61st. Ave. Main St. E. to University Ave[3]		3-1/2		6				4260	89	18			9	21.7	20.3	4.2	15-27	2.5	3.0	1967 1971		0
McKnight Rd. (White Bear Lk.) Cedar Ave. to Co. Rd. E (CSAH No. 12.[4]		4	2-5/8	2	8	SL FSL LFS FS	30-70	2935	76	36			7					2.5	3.4	1962		0
Humboldt Ave. No. (Brooklyn Center) 65th Ave. N. to 69th Ave. N.		8		3				7370	853	237								3.0	4.0	1973		7-1 2
Humboldt Ave. No. 69th Ave. N. to 70th Ave. N.		2		4				4330	517	144								2.5	3.8	1966		0
Humboldt Ave. No. 70th Ave. N. to 73rd Ave. N.		2		4				4330	517	144								2.5	3.8	1967		0
21st. Ave. (South St. Paul) 2nd St. So. to Wentworth Ave.		1-1/2	3	2	8	LS FG FSL and SIL	20-75	2315	73	34								1.9	2.3	1956		0
Polk St. N.E. (Blaine) 99th Ave. N. to Quincy Blvd.	0.97							2800	79	20								2.6	3.3			

[1] Seal coated in 1973, FA-3.

[2] Seal coated in some areas.

[3] Trap rock seal coat applied in 1973.

[4] Road has been seal coated several times.

APPENDIX C

INVESTIGATION 645
Research Implementation

PAVEMENT MAINTENANCE CRITERIA

SUMMARY

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Sponsored by
Minnesota Department of Transportation Project 645

INTRODUCTION

The cost of one inch of asphaltic concrete overlay is now approximately $10,000 per mile on the average. Pavement engineers therefore want to make sure that, first of all, the pavement that is to be overlaid is really in need of that overlay. Also, the engineer would like to be assured that with the investment in an overlay or some other type of maintenance the structure that is already there will withstand the expected traffic. Questions such as, "Will the additional investment last long enough to be justified?" or "Will a 2-in. overlay last 10 or 20 years, 10 or 20 months, or 10 or 20 days?", should be answered. Another question that could be asked, "Is a 2-in. or 4-in. overlay necessary or could one get by with just a leveling course or some other type of surface treatment?" There are many criteria and factors that will be involved in making the decision on a particular road. In fact the decision that is made on a given road will not only depend on its condition but also on the condition of other roads under the same jurisdiction.

In the last few years maintenance has become a much more important part of pavement engineering because fewer new roads are being constructed. With the many miles of surfaced roads that are now in existence it is necessary to be able to judge which ones should be maintained and what maintenance procedures are most appropriate. For all except the very smallest of jurisdictions, some type of a maintenance management system should be used to establish priorities.

It is with this in mind that the Steering Committee of Investigation 645 has chosen the subject of Pavement Maintenance Management. During the last few years work has been done as part of Investigation 645 to present rating systems and procedures which will make it possible to quantify some of the parameters needed to help make a judgment as to proper maintenance procedures.

So far four presentations have been developed and been presented around the State of Minnesota. These are:

1. Surface Condition Rating System
2. Rideability
3. Traffic
4. Strength

The Surface Condition Rating System presents a procedure for evaluating the characteristics of the bituminous surface only. By observing these and putting them into a rating scheme it has been possible to determine if a given pavement is in need of a surface treatment or seal coat or some other type of resurfacing.

The presentation on Rideability describes methods by which the roughness of the pavement can be converted into a rating from 0 to 5. This is defined in terms of the present serviceability concepts developed at the AASHO Road Test.

In the Traffic presentation a method is described which makes it possible to calculate the load effect on the pavement in terms of equivalent 18,000-lb single axle loads.

The Strength of the road is defined using two procedures. The first considers the type or strength of the embankment and the thickness of the pavement section layers. The second uses the Benkelman beam deflection test which gives a direct measure of the strength of the road at the time of the test. With these procedures it is possible to estimate the life of the road under the predicted traffic and also determine what the allowable load should be on that road during the critical spring period.

Each of the procedures presented uses concepts and equipment that are readily available to the cities and counties in the State of Minnesota. The procedures presented are either those used directly by the Minnesota Department of Transportation or are slightly modified from procedures which are used on the trunk highway system. It is recognized that there are other factors that will govern when and what is done to a particular pavement section. However, the parameters that are presented will help in the decision makers by making available more specific information on which to base their judgement.

This summary presentation is a brief resume of each of the parameters and procedures which have been presented. A method of summarizing this information into usable form is then suggested.

SUMMARY OF PARAMETERS

Surface Condition Rating System

The surface condition rating system includes procedures and suggestions for making a set of surface condition ratings. This information can be summarized on a surface condition rating form which has been provided and is included with that presentation. The conditions considered under this scheme are:

1. General Structural Condition
2. Surface Wear
3. Weathering
4. Skid Resistance
5. Uniformity
6. Crack Condition
   a. Opening
   b. Abrasion
   c. Multiplicity

Each of these eight conditions can be given a rating from 0 to 5 using the suggested descriptions that are presented in Table 1.

The General Structural Condition gives the rating of how good that pavement is performing structurally. The ride may be satisfactory, but it may still have some cracking and patching developing.

The Surface Wear is a measure of how much the pavement is being worn down by the effect of tires or how badly the pavement is bleeding.

The Weathering gives a rating of how deteriorated the surface is due to the affects of temperature, water and wind.

The Skid Resistance rating is suggested as a means of estimating skid resistance when a number from a skid trailer is not available.

The Uniformity rating gives an indication of how blotchy, streaked or nonuniform the surface looks generally.

The Crack Condition rating is a measure of how big the cracks are in width, how much they are abraided and whether there are associated multiple cracks along with the transverse or longitudinal cracks. Table 2 gives a brief listing of the descriptions of the general structural rating, Table 3 a brief description of the surface wear rating, Table 4 the weathering ratings, Table 5 the skid resistance ratings, Table 6 the uniformity ratings, and Table 7 the crack condition ratings. In the surface condition presentation some examples are given showing pictures of pavements which have been rated at the various levels of these conditions.

It is important that those who would wish to use this rating system do some practice rating before surveying a system of roads.

TABLE 1

GENERAL DESCRIPTION OF NUMERICAL RATINGS

Rating	Degree
5	None
4	Slight
3	Moderate
2	Severe
1	Deteriorated

TABLE 2

DESCRIPTION OF GENERAL STRUCTURAL CONDITION RATINGS

Rating	Description
5	New pavement, good condition, no cracks.
4	Cracking beginning to develop as longitudinal cracks in wheelpath.
3	Large pattern of cracks developed (map cracks).
2	Pattern smaller (alligator cracks).
1	Small pieces of pavement are thrown out by traffic (erosion).

TABLE 3

RATING FOR LEVELS OF PAVEMENT SURFACE WEAR
(a) ABRASION WITH NO SEAL COAT

Rating	Description
5	Mat uniform and original color across surface.
4	Coarse aggregate shows in wheelpath but not protruding.
3	Coarse aggregate shows in wheelpath and protrudes up to 1/16 in. or wheelpath is worn down up to 1/16 in.
2	Coarse aggregate protrudes in wheelpath more than 1/16 in., or mat is worn down more than 1/16 in.
1	More than 20 percent of coarse aggregate is kicked out in the wheelpath.

(b) ABRASION WITH SEAL COAT

Rating	Description
5	Surface uniform original color of seal coat across the surface.
4	Color lighter in wheelpath.
3	Up to 25 percent of seal coat aggregate kicked out in wheelpath.
2	Seal coat aggregate eroded away, showing original surface in the wheelpath.
1	Aggregate from original surface being kicked out in wheelpath.

(c) BLEEDING WITHOUT AND WITH SEAL COAT

Rating	Description
5	Mat uniform and original color across surface.
4	Surface dark in wheelpath due to mix appearing richer in wheelpath.
3	Bituminous material filling surface in wheelpath over 25 percent of length.
2	Surface richer and bleeding somewhat along more than one-half of the length in wheelpath.
1	Wheelpath rich and bleeding along entire length of pavement.

TABLE 4

RATINGS FOR LEVELS OF WEATHERING
(a) PAVEMENTS WITH NO SEAL COAT

Rating	Description
5.0	Bituminous surface original color except possibly in wheel-path.
4.0	Surface is color of surface aggregate, especially between wheelpaths.
3.0	Coarse aggregate protrudes between wheelpaths.
2.5	Random small cracks beginning to form, mostly between wheelpaths.
2.0	Random cracks developed into a pattern or blocks (not related to loading).
1.0	Coarse aggregate or chunks of surface being eroded out.

(b) PAVEMENTS WITH A SEAL COAT OR SURFACE TREATMENT

Rating	Description
5	Seal coat aggregate intact and in condition as constructed.
4	Seal coat aggregate appears "drier" between wheelpaths (up to 10 percent eroded off).
3	10 percent up to 50 percent of seal coat aggregate eroded off (both wheelpaths).
2	Seal coat aggregate is more than 50 percent eroded off be-tween wheelpaths, leaving only bituminous material covering the original surface.
1	Seal coat is essentially all eroded off and the original surface is beginning to erode.

TABLE 5

RATINGS FOR LEVELS OF SKID RESISTANCE
BASED ON VISUAL EXAMINATION

Rating	Description
5	Good, coarse surface texture.
4.5	Good, gritty surface texture.
4	Fair, coarse surface texture.
3.5	Fair, gritty surface texture.
3	Aggregate slightly polished or wheelpath slightly darkened with excess asphalt.
2	Aggregate polished or wheelpath darker due to excess asphalt.
1	Bleeding condition.

TABLE 6

RATINGS FOR LEVELS OF UNIFORMITY

Rating	Description
5	Good
4	Streaked
3	Crack-filling
2	Blotchy
1	Multiple Spot Patching

TABLE 7

DESCRIPTIONS OF RATINGS FOR TRANSVERSE AND LONGITUDINAL CRACKS
(a) OPENING

Rating	Description
5	Hairline or filled.
4	1/16 to 1/8 in. open
3	1/8 to 1/4 in. open
2	1/4 to 1/2 in. open
1	More than 1/2 in. open

(b) CRACK ABRASION OR EROSION

Rating	Description
5	No wearing back of cracks.
4	Slight wearing of edges (mortar).
3	Some coarse aggregate eroding out.
2	Crack eroded back 1/2 way through the surface mix.
1	Eroded more than 1/2 way through the surface mix.

(c) MULTIPLICITY

Rating	Description
5	No associated cracks.
4	A few associated random hairline cracks.
3	Map cracks developed, along with transverse and longitudinal cracks.
2	Alligator cracks developed, along with transverse and longitudinal cracks.
1	Multiple cracks have broken away from surface.

The ratings can be recorded on the surface condition rating sheet and then entered in Table 21 (page 27) which is a summary of the pavement conditions.

Rideability

For the pavement management procedures developed in Minnesota the rideability has been defined using the present serviceability concept. With this concept the rideability is defined as the ability of a section of road to serve the traffic that it was designed for. The rating is actually an average of the opinions of a group of individuals on how well that road rides based on a scale from 0 to 5. In the rideability presentation two procedures are suggested for determining the rideability of a given section of road.

1. Use of a rating panel.
2. Use of the PCA (Portland Cement Association) road meter.

The rideability can be estimated using as few as three raters. However, if more ratings or opinions are obtained this will give a better estimate of the rideability. The following nine rules should be followed if the rating panel system is to be used.

1. Use the following descriptions to define the ride as related to the numerical ratings.

   4 - 5 very good
   3 - 4 good
   2 - 3 fair
   1 - 2 poor
   0 - 1 very poor

Ratings between these descriptions (i.e. 2.4) can be used to indicate levels between those shown. The rater should ask himself how he or she would like to ride on a pavement like this all day. This guideline may not strictly apply to shorter county roads or city streets. However, an indication of how well that road is serving the public should be made.

2. The rater should disregard grade, alignment, right-of-way width, shoulders, ditch conditions, etc. and other conditions which do not directly affect ride or are governed by the structure of the pavement.
3. Ride the pavement sections at the posted speed limit.
4. Ratings should be made for each 1/2 mile in rural areas, and 1/4 mile in urban areas as it is difficult to remember the level of ride for longer distances.

5. There should be no discussion of ratings during a session if there is more than one rater in a car. There could be some discussion after a session, but it should be remembered that there is no absolute right rating. Two people will not necessarily judge the ride in exactly the same way.

6. The average rating for each 1/2 mile or 1/4 mile should be recorded as the present serviceability rating for that portion of

road. These distances need not be exact and if there are other limits which are appropriate they should be used.

7. Raters should go on practice runs periodically to help calibrate themselves. It would be good to have a series of roads in the area which are examples of high and low ratings to ride over periodically.

8. Ratings should be done in passenger cars in relatively good condition. The raters should also be in relatively good condition. (not tired, etc.)

9. Ratings on roads in good condition (3.0 to 3.5) or higher need only be taken every 2 or 3 years, whereas those with lower ratings (less than 3.0) should be rated about every year.

Use of the PCA Roadmeter

The PCA roadmeter is composed of a set of counters which accumulate the number of 1/8-in. deviations between a car axle and frame from a null position when driving over a section of road. The rating is done using a standard automobile. The PSR is determined using a relationship between counts and serviceability established for that vehicle. There are ten roadmeters available throughout the State of Minnesota, one in each Mn/DOT construction district and one in the Mn/DOT central office. When the roadmeter is used it should be recently calibrated. Rules to follow in the operation are included in an appendix to the Rideability presentation. Usually a Mn/DOT district will be able to run roadmeter ratings for cities or counties if enough lead time is allowed for scheduling. It may also be possible for three or four counties and/or municipalities to cooperate to obtain their own roadmeter. The devices are available commercially or can be built and installed in any standard car using plans available from MnDOT.

After the present serviceability rating is determined either using a panel or the PCA roadmeter this value should be entered in the appropriate place on the Summary of Pavement Conditions Sheet which is Table 21 (page 27).

Traffic

On the Summary of Pavement Conditions Sheet there are four entries for traffic. The first is the AADT which is the total two-way average annual daily traffic. This value can be obtained either from a traffic flow map for the city of county, or can be determined by a traffic study on a road considered to have similar traffic or if it is an existing road, on that given road. To calculate the one way AADT the two way value is usually multiplied by 0.5 for two-lane roads or 0.45 for four-lane roads. The speed on that road should also be recorded.

The equivalent 18,000-lb single axle loads (ΣN18) should then be determined using one of the methods given in the traffic presentation. The procedure is summarized on the calculation sheet which has been provided with that presentation and as Table 8 herein. The parameters that are required for this calculation are the AADT, the distribution of vehicles, the

TABLE 8

VEHICLE TYPE DEFINITIONS FOR EQUIVALENT LOAD CALCULATION

Vehicle Type Number	Description
1	Passenger Cars
2	Panel and Pickups (under one ton)
3	Single Unit; 2-axle, 4-tire
4	Single Unit; 2-axle, 6-tire
5	Single Unit; 3 axle
6	Tractor Semitrailer Combination; 3 axle
7	Tractor Semitrailer Combination; 4 axle
8	Tractor Semitrailer Combination; 5 axle
9	Tractor Semitrailer Combination; 6 axle
10	Trucks and Trailers Combinations plus Buses

average effect of each vehicle at that location, and some indication of a growth factor for that area. The AADT can be determined as indicated previously using a traffic flow map. The distribution of vehicles can be determined either by making a vehicle type study on the road being proposed for maintenance, on a similar road, or an assumed distribution could be used.

If a vehicle type survey is to be made, it is conducted for 16 hours on two consecutive weekdays other than Monday or Friday. The survey should be made from 6 AM to 2 PM on one day and 2 PM to 10 PM on the next. Vehicles are classified according to the types listed in Table 8 which are used for classification by the Planning and Programming Section of Mn/DOT. The results of the 16-hour count are listed in Column 2 of Table 9. These values are then modified with the seasonal adjustment factors listed in Table 10. The appropriate factors are entered in Column 3. The seasonally adjusted number of each type vehicle (Column 4) is obtained by multiplying Column 2 by Column 3. The seasonally adjusted percentage is then calculated by summing Column 4 and taking each truck type as a percent of the total.

If it is not possible to run a traffic survey, then assumed percentages listed in Table 11 can be used. Some judgment should be used in modifying these values if it is felt there is some appropriate variation to use. The design lane AADT has been determined and entered in Column 6. The design lane distribution is then calculated for each vehicle type by multiplying Column 5 by Column 6 for each vehicle type.

The average effect of each vehicle type on the performance of the road is called the N18 Factor. This can also be considered the number of equivalent 18,000-lb single axle loads on the average imparted to that pavement each time one of that type vehicle passes a location. Table 12 is a listing of average N18 Factors for 7-ton and 9-ton roads in Minnesota. For specific situations these factors can be modified in consultation with a knowledgeable traffic engineer. The N18 Factor for each vehicle type is entered in Column 8 of Table 9. To calculate Column 9 which is the Design Lane Daily N18 for each vehicle type each entry in Column 7 is multiplied by the respective value in Column 8. The summation of Column 9 is then the total Daily N18 at present for that road.

The number of years to be used for design is then entered along with an estimated percent growth on the bottom of Table 9. Time-growth factors for 10 and 20-year periods are listed in Table 13 for various rates of growth. As indicated in the table a growth of 0.5 percent is suggested for 7-ton roads and 3.5 percent for 9-ton roads. Again, if the conditions warrant it, other design periods and/or annual growth rates can be used. The time-growth factor is an annuity factor and thus can be found in standard annuity tables.

The ΣN18 for the design period is then calculated by multiplying the daily N18 by 365 and multiplying that product by the Time-Growth Factor. This value should be entered in the appropriate location in Table 21.

In the traffic presentation there is an example worked out to show how the calculations for Σ N18 can be made. This example calculation is included on pages 21 through 24 of the traffic presentation.

TABLE 9

CALCULATION SHEET FOR

EQUIVALENT 18,000-lb AXLE LOADS

Date ____________

Road Location ______________________ No. Lanes ________ Design Lane ________

Design Lane AADT; ______________ Map ☐ Count ☐ Other ________

Vehicle Distribution; Assumed ☐ Manual Count ☐ Machine Count ☐ Other ________

1	2	3	4	5	6	7	8	9
Vehicle Type	16 hour Count	Adjustment Factor	Seasonally Adj. No.	Season. Adj. Percent	X Design Lane ADT	Design Lane Distribution	X N18 Factor	Design Lane Daily N18
1					X		X	
2					X		X	
3					X		X	
4					X		X	
5					X		X	
6					X		X	
7					X		X	
8					X		X	
9					X		X	
10					X		X	
Totals								

Design Number Years ____________

Percent Growth ____________

Design ΣN18 = 365 x (Daily N18) x (Time Growth Factor)

= 365 (   ) x (   ) = ☐

TABLE 10

SEASONAL ADJUSTMENT FACTORS FOR VEHICLE TYPES

Data Taken	Vehicle Type						
	1-3	4	5	6	7	8-9	10
Jan.-April	1.45	0.81	1.68	0.88	0.87	1.01	0.95
May-August	0.96	0.78	0.76	0.77	0.73	0.96	0.90
Sept.-Dec.	1.27	0.78	0.92	0.73	0.91	0.95	1.07

TABLE 11

ASSUMED PERCENT DISTRIBUTIONS

Vehicle Type	7-Ton	9-Ton
1	76.5	78.1
2	15.2	10.0
3	2.0	1.4
4	3.7	3.9
5	1.0	1.3
6	0.1	0.3
7	0.1	0.5
8	0.5	3.0
9	-	-
10	0.9	1.5

TABLE 12

AVERAGE N18 FACTOR BY VEHICLE TYPE

Vehicle Type	Load Limit 7-Ton	Load Limit 9-Ton
1	0.0004	0.0004
2	0.007	0.007
3	0.01	0.01
4	0.17	0.19
5	0.55	0.48
6	0.37	0.60
7	0.43	0.84
8	1.00	1.50
9	--	--
10	0.33	0.33

TABLE 13

TIME-GROWTH FACTORS FOR 10 AND 20 YEARS

Annual Growth %	10 Years	20 Years
0	10.00	20.00
0.5*	10.23	20.98
1.0	10.46	22.02
1.5	10.70	23.12
2.0	10.95	24.30
2.5	11.20	25.54
3.0	11.46	26.87
3.5**	11.73	28.28
4.0	12.01	29.78
4.5	12.29	31.37
5.0	12.58	33.07
5.5	12.88	34.87
6.0	13.18	36.79

* Suggested annual growth for 7-Ton roads.

** Suggested annual growth for 9-Ton roads.

Strength

In the fourth presentation the strength of a pavement section is defined using two methods. These include using either the structure of the pavement section or using a direct measure of strength which for the State of Minnesota has been defined using the Benkelman beam deflection test.

The definition of strength is related to the number of equivalent 18,000-lb single axle loads that the road can take before the serviceability is reduced to some level defined as failure. For most state highways this level is taken as the PSR or serviceability level of 2.5. However, for lower traffic city and county roads this level may be taken as a serviceability level rating of 1.5.

Strength Defined Using Pavement Section

One method of measuring the strength is using the pavement structure. The pavement structure is made up of the embankment and the various layers of base and surfacing. In order to determine the structure by this method it is necessary to know the type or strength of embankment and the thickness of the layers broken down into subbase, base and surface. This information can be obtained from records or by making borings.

For the embankment the stabilometer R-value must be determined. If the R-value has not been run on the given soil in the laboratory, it can be estimated using the AASHTO classification or the textural classification with Table 14 which is Table F of the Mn/DOT Road Design Manual.

The layer thicknesses are converted to granular equivalent thicknesses for the section using the G.E. factors listed in Table 15 which is Table D of the Mn/DOT Road Design Manual. The granular equivalent can then be calculated with the following formula: $G.E. = a_1 D_1 + a_2 D_2 + a_3 D_3$. The values of a_1, a_2, and a_3 can be obtained from Table 15. If a pavement section is deteriorating, then some judgment has to be used to estimate what factor is appropriate for that layer. The R-value and granular equivalent thickness should be entered in the appropriate location in Table 21.

Using the R-value and the granular equivalent thickness for a given pavement section the present Mn/DOT design chart for flexible pavements can be used to estimate how much traffic the section should be able to withstand before the serviceability level has dropped to 2.5.

Estimation of Strength Using the Benkelman Beam Deflection Test

One of the direct measurements of strength using a load test is the Benkelman beam deflection test. For this test a known axle load can be run over the pavement section and the deflection under that load measured. An advantage of this approach for estimating strength over the granular equivalent method is that moisture conditions and other local variations are taken into account. A disadvantage is that there are different levels of flexibility of pavements and therefore what would be a critical deflection level for one may not be for another.

The testing equipment and operational procedures for running the Benkelman beam deflection tests are given in Appendix A of the fourth

TABLE 14

STABILOMETER R-VALUES BY SOIL TYPE*

There may be occasions, such as small projects, where it will be impractical to obtain and run "R" value samples. In such cases it may be possible to assume an R-value if the AASHTO soil type and geologic origin of the soil is known. The following is a tabulation of suggested values and comments.

AASHO Soil Type	Textural	Assumed R-Value	Comments
A-1	Sands Gravels	75	Excellent confidence in using assumed value.
A-1-b	Sands Sandy Loams (non plastic)	70	If percent passing number 200 sieve is 15 to 25 percent, R-value may be as low as 25. In such cases, it is highly desirable to obtain laboratory R-values.
A-2-4 & A-2-6	Sandy Loams (non plastic, slightly plastic, or plastic	30 (70 for LS and LFS)	Loamy Sands and Loamy Fine Sands commonly have R-value of 70. Laboratory R-values range from 10-80 for the entire A-2 classification. It is highly desirable to obtain laboratory R-values for the Sandy Loams. See Table E for sampling frequency.
A-3	Fine Sands	70	Excellent confidence in using assumed value.
A-4	Sandy Loams (plastic) Silt Loams Silty Clay Loams Loams Clay Loams Sandy Clay Loams	20	Laboratory R-values range from 10 to 75. It is highly desirable to obtain laboratory R-values. See Table 12 for sampling frequency.
A-6	Clay Loams Clays Silty Clay Loams	12	Laboratory R-values commonly occur between 8 and 20.
A-7-5	Clays Silty	12	Data available are limited.
A-7-6	Clays	10	Laboratory R-values commonly occur between 6 and 18.

* Based on data collected by MHD through 1974.

NOTE: In using the above assumed R-values for flexible pavement design it is essential that the subgrade be constructed of uniform soil at a moisture content and density in accordance with Mn/DOT Spec.2105. To minimize frost heaving and thaw weakening it is also essential that finished grade elevation be placed an adequate distance above the water table. This distance should be at least equal to the depth of frost penetration. In the case of silty soils the distance should be significantly greater.

TABLE 15

GRANULAR EQUIVALENT (G.E.) FACTORS

All bituminous and aggregate courses are converted to an equivalent thickness of Class 6 Aggregate Base (denoted as granular equivalent = G.E.) using factors listed below.

Material	Specification	G.E. Factors
Plant-Mix Surface	2341, 2361	2.25
Plant-Mix Surface	2331	2.00
Plant-Mix Binder	2331	2.00
Plant-Mix Base	2331	2.00
Road-Mix Surface	2321	1.50
Road-Mix Base	2321	1.50
Bituminous Treat. Base	(Rich) 2204	1.50
Bituminous Treat. Base	(Lean) 2204	1.25
Aggregate Base	(Cl. 5, Cl. 6) 3138	1.00
Aggregate Base	(Cl. 3, Cl. 4) 3138	0.75
Selected Granular Material		0.50*

* May be used in design when so approved by Central Office Soils Section.

NOTE: Where the subgrade consists of granular material the District Materials and/or Soils Engineer may recommend the treating of the upper portion of the selected granular material with 1" or 2" of stabilizing aggregate (Specification 3149.2C) or treating the upper 3 inches with 0.2 Gallon/Square Yard/Inch of Asphalt Emulsion, SS-1.

presentation. These procedures are taken directly from MHD Investigation 603 in the 1968 Summary Report entitled "Flexible Pavement Evaluation with the Benkelman Beam" pages 11 to 16. The procedure outline gives the equipment and procedures required to obtain deflections every 500 to 1,000 ft.

With the deflections determined by the method given in Appendix A it is then necessary to calculate the design deflection which represents a given section of road (usually taken as a mile). In order to do this the following variables are considered.

1. Temperature
2. Time of Year
3. Load
4. Thickness of Layers
5. Strength of Embankment
6. Variability Measurements

The temperature is corrected by using Table 16 which shows the temperature correction to 80 F for deflections run at other temperatures. The deflections are corrected only for tests at a temperature less than 80 F.

Deflections are converted to a critical spring value using the factors in Table 17. The ratios are dependent upon the time of year and the thickness of the asphalt layer in the pavement section.

The axle load on the test vehicle used is typically a 9-ton or a 7-ton axle. It is important to know what the load is. Then deflections can be calculated for other loads by taking an arithmetical ratio of the loads. Using the spring ratios a spring deflection for that section of road is determined.

Table 18 shows allowable deflections for various thicknesses of bituminous surface and levels of traffic. The allowable spring axle chosen from the table, the axle load used for the deflection test and the design spring deflection are substituted in the following formula to calculate the allowable spring axle load in tons.

$$L_A = L_B \times \frac{\text{allowable deflection}}{\text{design spring deflection}}$$

Where: L_A = Allowable axle load

L_B = Test vehicle axle load

This calculation can be made for each of the deflections run on the section of road.

It is also possible to estimate the life of a flexible pavement section based on the design spring deflection. The first steps of Appendix B yield the design spring deflection for each mile of road. Again, if the deflection is run using a 9-ton axle load, 7- and 5-ton deflections for the same section of road can be obtained by multiplying by 7/9 and 5/9ths respectively. The

TABLE 16

TEMPERATURE CORRECTION TO 80 F FOR BENKELMAN BEAM DEFLECTIONS

Range of Defl. in Inches	Temperature in Degrees F				
	to 35	36-45	46-55	56-65	66-75
.000 - .010	.005	.004	.003	.002	.001
.010 - .020	.007	.006	.004	.003	.001
.020 - .030	.010	.008	.006	.004	.002
.030 - .040	.010	.008	.006	.004	.002
.040 - .050	.012	.010	.007	.005	.002
.050 - .060	.015	.012	.009	.006	.003

TABLE 17

BENKELMAN BEAM DEFLECTION RATIO TABLE

Deflection ratios to approximate critical spring deflections from deflections taken during other non-frozen times of the year for:

PLASTIC EMBANKMENTS

Asphalt Surface Thickness	Date of Test				
Conventional Construction	Aug. Sept.	July	June	May 16 to May 31	May 1 to May 15
$\leq$ 3-1/2 in.	1.73	1.64	1.52	1.32	1.14
$>$ 3-1/2 $\leq$ 5-1/2 in.	1.68	1.54	1.40	1.24	1.14
$>$ 5-1/2 $\leq$ 8 in.	1.49	1.28	1.25	1.25	1.17
$>$ 8 in.	1.37	1.16	1.14	1.18	1.13
Full-Depth Construction					
$>$ 8 in.	1.45	1.12	1.13	1.16	1.12

SEMI-PLASTIC EMBANKMENTS (L, Sil, and sl. pl. SL)

Asphalt Surface Thickness	Date of Test				
	Aug. Sept.	July	June	May 16 to May 31	May 1 to May 15
$\leq$ 5 in.	1.46	1.52	1.45	1.35	1.16
$>$ 5 in.	1.68	1.56	1.48	1.40	1.29

NON-PLASTIC EMBANKMENTS (S, S & G, FS, and LFS)

Asphalt Surface Thickness	Date of Test				
	Aug. Sept.	July	June	May 16 to May 31	May 1 to May 15
$\leq$ 2 in.	1.88	1.83	1.76	1.41	1.30
$>$ 2 $\leq$ 5-1/2 in.	1.48	1.57	1.50	1.36	1.21
$>$ 5-1/2 $\leq$ 8 in.	1.10	1.05	.99	1.02	1.00

NOTE: Critical deflections correspond to maximum deflections which occur in the spring, during which the pavement is most likely to be damaged by heavy loads.

This ratio table is based on a continuous ten year record (1964 - 1973) of measured rebound deflections taken throughout the year on various Minnesota pavements.

TABLE 18

ALLOWABLE SPRING DEFLECTIONS

Traffic					
two-way	HCADT*	< 50	50-100	100-150	> 150
two-way	ADT**	< 500	500-1000	1000-3000	> 3000
Bituminous Surface Thickness		Allowable Deflection, inches			
less than 3 in.		0.075	0.070	0.060	0.045
3 to 6 in.		0.065	0.060	0.050	0.040
greater than 6 in.		0.055	0.050	0.040	0.035

* HCADT = heavy commercial average daily traffic volume (excludes passenger cars and 4-tired trucks).

** Use AADT only when HCADT is not known.

design equation presently used to predict pavement life based on the Benkelman beam deflection is the following:

$$\text{Log } \Sigma N18 = 11.06 - 3.25 D_S$$

Using the 9-ton, 7-ton and 5-ton deflections it is possible to calculate a ΣN18 value for each of the load restrictions. The assumption in each case would be that the maximum deflection represents a situation where the load would be restricted to 9, 7, and 5-tons during the critical spring period.

Table 19 shows the solution to the performance equation for various design spring deflections. As would be expected if the road is restricted to a lower load during the critical spring period, it will theoretically be able to carry a greater number of total equivalent 18,000-lb axle loads.

By comparing the number of ΣN18 predicted from the deflection tests with the number of years to accumulate that level of traffic from the previous calculations, the number of years of life to a serviceability level of 2.5 for that section of road can be estimated.

Table 20 is a worksheet which can be used to summarize the calculations for design spring deflections, allowable tonnages and estimated road life. This table is set up to use each deflection measured. By using this procedure the variation in pavement strength in terms of tonnage and predicted life can be observed. It is also possible to calculate the average and standard deviations of the deflections in one mile and calculate tonnages and road life for an average plus two standard deviation values. This could also be done for the calculated tonnages within each mile. It is suggested that the latter procedure be used because it would then be possible to see what areas within the mile are low in strength. It may be possible to upgrade the whole section by strengthening relatively short segments of the roadway.

Summary of Conditions

So far in this presentation procedures have been summarized for determining the surface condition, calculating the traffic factor in terms of equivalent 18,000-lb single axle loads, determining the rideability in terms of serviceability rating of a pavement section and estimating pavement life or strength using the pavement structure and a direct measure of strength of a pavement. Table 21 is an example of how this information might be summarized. An attempt has been made to put as much information as possible on one sheet of paper for a given pavement section. A brief discussion of how to fill out this table follows.

Under the heading of General description of the pavement section the approximate date at which the evaluation is being done, year the road was constructed and the year it was overlaid are entered.

Under the Structure the type of surface base and subbase are listed, along with the thicknesses of each. These can be obtained from either records in the office or by measuring with borings in the field. The

TABLE 19

SOLUTION TO PERFORMANCE EQUATION PREDICTING
EQUIVALENT LOADS TO PSR = 2.50

$$\text{Log } \Sigma N18 = 11.06 - 3.25 \log D_s$$

Where $\Sigma N18$ = Equivalent 18,000 lb single axle loads

D_s = Design Spring Deflection, 0.001 in.

Deflection, 0.001 in.	$\Sigma N18$	Deflection, 0.001 in.	$\Sigma N18$
20	6,800,000	75	92,500
25	3,300,000	80	75,000
30	1,800,000	85	61,600
35	1,100,000	90	51,100
40	710,000	95	43,000
45	490,000	100	36,300
50	345,000	105	31,000
55	253,000	110	26,600
60	191,000	115	23,100
65	147,000	120	20,100
70	116,000	125	17,600

TABLE 20

Calculation of Design Spring Deflections and Allowable Tonnages

Road Description ______________________ Mile __________

Thicknesses D_1 ______ D_2 ______ D_3 ______ G.E. __________

Embankment : Type ____________ R-Value __________

Traffic AADT __________ Σ N18 __________ Year Blt. or O.L. to present

Σ N18 __________ 20 - yr life

Date of deflection tests ____________ Deflection Test Load __________

est o.	Measured Defl.	Mat Temp.	Temp. Corr.	809 Defl.	Spring Ratio	Design Spring Defl.	Allow. Defl.	Calc. Tonnage	Σ N18 5-ton	Σ N18 7-ton	Σ N18 9-ton

Ave. Design Spring Defl. __________ Defl + 2 SD __________

Std. Deviation __________ Allow Load __________ granular equivalent factors are obtained using Table 15 as a guide. The granular equivalent for each of the layers is then calculated by multiplying the thickness by the respective factor. The total granular equivalent is calculated by adding up the values for each of the layers. The embankment R-value can be either obtained by running an R-value test on the soil in the lab or by estimating the R-value using either the AASHTO soil classification or a textural classification from Table 14.

The Traffic Factors listed are first the AADT which can be obtained as indicated in the traffic presentation either from a flow map or by making a 16-hr count. The speed of the section of road is the speed limit. The equivalent loads in terms of 18,000-lb single axle loads should be determined since construction or the last structural overlay. This can be done using the techniques and the calculation chart from the traffic presentation. The traffic to 20 years of age or any other age can be obtained using those procedures. The road conditions are first of all defined using the present serviceability rating which is obtained either with the PCA roadmeter or a panel using procedures outlined.

The surface conditions are those obtained with the surface condition rating scheme which is summarized in this presentation and discussed more fully in the first presentation.

The rut depth can be determined using either the A-frame or by running a stringline across the road to see what the depressions are in the wheel path.

The Strength and Life Predictions portion of Table 21 summarizes the two methods suggested for estimating the years of life with the existing pavement section. The first part uses the structure and the embankment strength to determine first the N18 that this structure could withstand according to the present Mn/DOT Design Chart. This can be read directly from the chart when the granular equivalent and the R-value of the embankment are either measured or estimated. To determine the number of years to accumulate this ΣN18 a table or plot of the predicted accumulation of ΣN18 can be used which compares the predicted number of loads to 2.5 serviceability level with the accumulation predicted with time. This can be obtained using the calculations from the traffic presentation. In the next part of Table 21 the Benkelman beam deflection information is used to predict the life of the pavement again without any structural overlay or improvement. The ΣN18 predicted in this manner is the ΣN18 for the total life of the pavement. Therefore if the pavement is presently 10 years old and its total life is estimated to be 22 years, then it can be assumed there is 12 years left before the PSR will drop to 2.5. The 9-, 7- and 5-ton deflections are calculated as given in the fourth presentation. The ΣN18 values will be greater for the 5-ton deflection than for the 9-ton deflection because the lower deflection will result in a longer predicted life. The years to accumulate this traffic then can be obtained in the same way as for the prediction of life for the structure by looking at the relationship of the accumulation of traffic with years under the traffic level using the traffic calculations.

TABLE 21. SUMMARY OF PAVEMENT CONDITIONS

GENERAL

Location ______________________ Date ____________

Year Constructed ______________ Last Overlaid ____________

STRUCTURE

Type	Thickness in	G.E. Factor	G.E.
Surface, (D_1)	______	______	______
Base, (D_2)	______	______	______
Subbase, (D_3)	______	______	______
TOTALS -		-	G.E. = ______

Embankment R-Value ______ Laboratory / Estimated

TRAFFIC

AADT ______

Speed ______

Equivalent Loads ($\sum$N18)

Since last O.L. or construction ______

Future

5 yr. ______ 10 yr. ______ 20 yr. ______

CONDITIONS

PSR ______ Roadmeter / Panel

Uniformity ______

Surface Condition

Structural ______

Surface Wear ______ Abrasion / Bleeding

Weathering ______

Skid Resistance ______ Number / Rating

Crack Conditions

Opening ______

Abrasion ______

Mult. ______

Rut Depth, in. ______

STRENGTH AND LIFE PREDICTIONS

Structure

N18 from Design Chart ______

Years to accumulate
Assuming O.L. ______

Recommended Action ______

______

Est. Cost ______

Benkelman Beam
Deflection Predictions

Spring Defl. (.001 in.)	$\sum$N18	Yrs.
9 T		
7 T		
5 T		

Present Restricted Tonnage based on Mn/DOT 603 Procedure

______ tons

SUMMARY OF PROCEDURES FOR COMPLETING
TABLE 21 SUMMARY OF PAVEMENT CONDITIONS

GENERAL:

The location of the road should give the number, designation and define the limits and length of road being considered. The length considered should represent a logical portion which would be maintained or reconstructed as a unit and is reasonably constant relative to conditions and traffic.

The date should represent the date on which the evaluations and traffic are determined. These will not be necessarily the same day, but could represent a month or so period in which the work was done.

The date constructed and/or overlaid can be obtained from records.

STRUCTURE:

The thickness of surface, base and/or subbase and any additional layer can either be determined from construction records or measured when augering.

The G.E. Factor is determined from Table 15 for the particular material in each of the layers.

The G.E. is calculated by multiplying the thickness by the G.E. Factor. The G.E. column is then added up to give the total structure for that pavement section.

The embankment R-value is determined either in the laboratory or estimated for the soil classification using Table 14.

TRAFFIC:

The AADT is obtained either from a traffic flow map or a traffic survey as described on page 14. The speed is the posted speed limit.

The equivalent loads (ΣN18) can be calculated by first calculating the present daily ΣN18 using the procedure and tables on pages 14-20 and summarized in Table 9. This information may also be obtained from the Planning and Programming Division of Mn/DOT or the District traffic engineer.

The total ΣN18 since last overlay can be calculated using tables of "Present Value of Annuity". A percent decrease into the past and the number of years are used to determine a factor which when multiplied by the present daily N18 times 365 will give the summation. The future traffic can be calculated in the same manner with an annuity table using the number of years and an assumed percent increase in N18. This total can be determined for 5, 10, 20 years or other times into the future.

CONDITIONS:

The PSR is determined using either a panel or the PCA Roadmeter using the procedures presented on pages 11-13.

The surface condition ratings are established using the procedures and descriptions outlined on pages 4-10.

STRENGTH AND LIFE PREDICTIONS:

To make a life prediction based on structure, the ΣN18 from the Mn/DOT design chart is first determined using the G.E. and embankment R-value from the upper part of the table. This is an estimate of the N18 this structure should withstand before the PSR is reduced to 2.5 or a level where an overlay would be considered.

Using this value the years to accumulate this traffic assuming the pavement is overlaid now is determined by comparing the accumulation of equivalent loads from the present time to the total from the design chart.

An estimate of the number of years until an overlay would be needed can also be made by accumulating the ΣN18 from last construction or overlay and seeing when this value equals the value from the design chart.

The spring deflections, (9T, 7T and 5T) are determined using the procedures and tables on pages 24-27. This value should be a reasonable design value for the section of road. The variation in deflection along the length of road should be considered when determining the design deflection. It may be that there could be two or more deflection values which represent different segments of the road possibly where different soils occur. Table 20 could be used to summarize the deflections for these comparisons.

Predictions of the ΣN18 to a PSR of 2.5 from the deflections can be estimated using Table 19. This value will increase as the deflection goes down for the lower loadings.

The number of years to accumulate this traffic can be estimated by comparing the ΣN18 to a serviceability level 2.5 with the calculation of traffic accumulation estimated in the Traffic portion of Table 21.

The restricted tonnage based on the Mn/DOT procedure is determined using the measured spring design deflection and the allowable deflections listed in Table 18.

The information summarized in Table 21 can be used to determine if some type of maintenance is needed on this length of road and to some extent what procedure would be most appropriate. The criteria for how these are applied are based on other conditions such as finances and relative conditions of other roads under the same jurisdiction.