A PAVEMENT MANAGEMENT RESEARCH PROGRAM FOR OREGON HIGHWAYS

FINAL REPORT

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by

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16. Abstract

An extensive program was developed to measure pavement deflection skid resistance, and rideability throughout Oregon. The data from those "objective" measures were then evaluated for correlations with observed pavement distress and traffic factors.

It is concluded that "Dynaflect" deflections and other "objective" measures of pavement performance can best be used on the project level. The mechanized data gathering methods evaluated here have not proven valuable in network level pavement management.

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Foreword

This report and the attachments, represent the present state of pavement management research in Oregon. This is a composite of the work by several individuals over a 9-year period, each adding to the pool of knowledge. These individuals are:

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DISCLAIMER

ABSTRACT

In the late 1970's, inflating construction costs and declining highway gas tax revenues combined to reduce the amount of money available for highway maintenance and construction. It was in the face of this severe funding shortage that the idea for a pavement management system was first conceived.

Prediction of Pavement Deterioration

Present AC pavements are a composite of the surfaces that were in place before the latest treatment. This contributes to a high degree of variability in pavement structure and life expectancy. Prediction of pavement life with an acceptable amount of accuracy has not been possible. With a long-term data base, prediction could become acceptable and statistically valid.

The design procedure uses a target pavement life based on struc-tural factors. This prediction should be as valid as the assumptions and parameters used in the design process, construction quality control, and timeliness of required maintenance.

Life-cycle costs and Effectiveness

Better information should emerge from the Strategic Highway Research Program's (SHRP) Long Term Pavement Performance Study (LTPPS) which would monitor pavements for up to 20 years. The LTPPS program would include data from other states into a comprehensive data base that could provide significant life cycle estimates.

Development of State-wide Monitoring Sites.

At this time the development of representative pavement deflection sites for system pavement types is not a cost effective strategy. The reliability of the predictions would be of questionable value. It may be possible to develop representative sites using other objective criteria.

Development of a Pavement Management System.

At the Network level, Oregon is using a 'knowledge based expert' system that combines visual assessment of levels of distress in the pavement with 'expert' opinion on the pavement condition, history, and future needs. This data, combined with the traffic loadings, etc. incorporated into a Pavement Management System Index (PMSI) that becomes the basis for further analysis and projection of pavement life.

At the Project level, the Surfacing Design Unit is implementing the 1986 AASHTO pavement design procedure. This uses deflection, ride, cracking, and rutting as some of the objective measures of pavement strength and distress.

ABSTRACT (Cont.)

CONCLUSIONS

The Dynaflect deflection device does not, by itself, meet the needs for pavement management data. The pulse energy from a Dynaflect is not enough to disturb the heavier pavement sections.

The sole reliance on rideability data as a basis for pavement management, outside of the maintenance or short-term areas, does not appear to be warranted in Oregon when most pavements have average or better ride scores.

The sole reliance on single pavement data elements as a basis for pavement management, outside the maintenance or short-term areas, does not appear to be warranted in Oregon.

Early failure of many pavements in Oregon is probably due to factors other than those related purely to strength. This leads to the conclusion that, although the pavement design process is valid, factors such as construction quality control may be significant in the overall pavement management process.

The present pavement management system in Oregon appears to provide the needed network analysis in a cost efficient manner. It either directly, or indirectly, includes many of the factors in pavement life.

It may be possible to construct a pavement management model using a combination of more 'objective' methods of predicting pavement life. This will be possible when the methods of gathering multiple data elements simultaneously become reliable and cost effective. Should the new methods of assessing pavement distress and other objective factors using automated techniques prove effective and economical, their use would be considered and implemented.

At the project level, the past and present design procedures have provided for durable pavements in Oregon. This process is constantly revised to maintain state-of-the-art procedures. At this level, 'objective' data such as deflection, etc. are cost-effective when used on a project-by-project basis and should be fed back into the Pavement Management System to verify or validate the data base.

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INTRODUCTION

In the late 1970's, inflating construction costs and declining highway gas tax revenues combined to reduce the amount of money available for highway maintenance and construction. It was in the face of this severe funding shortage that the idea for a pavement management system was first conceived. Although recent increases in the Oregon gas tax and a decline in the inflation rate have moderated this problem, continued demand for quality transportation facilities requires that transportation agencies make optimum use of every available dollar. Since many alternate strategies can be employed to provide a serviceable roadway, it is important that a highway agency has the ability to differentiate between these strategies and to select the most cost-effective method of providing a high quality roadway over the entire life cycle.

Historically, the treatments used to maintain highways have been based on rational design assumptions. The quality of the Oregon Highway System indicates that these judgments have been sound.

At the Network level, there have been a few, somewhat limited, methods to determine if the given treatment provided optimum benefit, or if treatment of another section would be relatively more beneficial. The collection of needed research data on pavement condition, treatment cost-effectiveness, and life cycle costs, and the integration of this data into a pavement management system would provide an improved method for making these determinations in the future. Future improvements to the Pavement Management System should be driven by system performance and design needs for analysis.

At the Project level, the design process has used some of the above data in selection and design of specific pavement treatments.

The present research project was initiated in response to the need for a statewide pavement management system. This report documents the research findings.

INTRODUCTION

Pavement Management System Definition

A comprehensive Pavement Management System provides the best allocation of available pavement resources to ensure continued high levels of serviceability for an agency's pavements.

A Pavement Management System operates in several different areas. These areas can be defined as follows:

LONG RANGE --- Long-term projections of needs, funding levels, political priorities, etc. The time frame for this level could be defined as 10 - 30 years, or beyond the average design life of a pavement. The rebuilding and modernization of facilities comes in this area. This area usually includes the high-cost pavement strategies. This could be considered to be a network level activity.

MEDIUM RANGE - Medium-term strategies to maintain the serviceability of pavements until such time as Long-term strategies are cost effective. The time frame for this area is 5 - 10 years. These are considered to be medium cost solutions to pavement problems. This area includes structural overlays and recycling projects. This area includes elements of both network and project level activities.

SHORT RANGE -- Short-term strategies to preserve the state of the pavement at an acceptable level until medium cost treatments become cost effective. This area includes chip seals and thin overlays. The time frame for this area is 1 to 5 years. These strategies tend to be low cost.

MAINTENANCE -- This is the day-to-day work needed to keep the pavements usable by the motoring public. This includes pothole patching, crack sealing, and other low-cost activities.

DESIGN ------- The process by which the individual pavements are designed to meet strength, service life, and loading criteria. Design criteria are a part of all the other levels and, to an extent, determine the level of a particular treatment. This level uses many of the physical data elements to determine life expectancy.

SCOPE OF PROJECT

The initial scope of work had two major objectives. These were:

1. To develop a pavement management system which will monitor pavement condition and aid in programming the most cost-effective pavement rehabilitation treatments.

2. To determine the typical useful performance model of various pavement designs, the rate of deterioration of pavement rideability and strength, and the critical point in pavement life when rehabilitation or reconstruction is needed to preserve the initial pavement investment.

Because the responsibility for the development of the pavement management system was transferred to the Pavement Management Task Force, utilizing the staff resources of the Highway Division Planning Section, the research project scope of work was revised to reflect this change.

The pavement management system was designed to use existing and ongoing pavement condition surveys as a basis for the network portion of a pavement management system. This system was then used to develop program levels. The Research Section was to explore the use of new, objective (based on deflection or ride), data in an expanded long-term pavement management system. A major objective was to determine the cost-effectiveness of using an objective based data system.

SCOPE OF PROJECT

The major components of the present Research Section work plan were:

1. Review of published literature for reports useful to the refinement of the pavement management system by utilizing objective measurement data such as deflection, roughness cracking, patching, and rut depth.

2. To continue the measurement of pavement deflections on the statewide system of pavement monitoring sites until adequate data is available to determine the viability of developing pavement performance models.

3. To organize the existing and on-going collection of the pavement condition data listed in #2 into a computerized file system for statistical analysis.

4. To correlate pavement condition parameters such as surface roughness, skid resistance, and deflection with other pavement distress parameters such as percent cracking, rut depth, pavement age, and equivalent axle loads derived from available traffic data; and, to determine which relationships, if any, can be used to predict future pavement performance, and the need for further maintenance.

5. To predict the rate of deterioration of Oregon pavements so that pavement sections can be programmed for rehabilitation before more extensive deterioration occurs.

6. To determine the comparative cost-effectiveness of various pavement treatment strategies so that an optimal program of pavement maintenance and rehabilitation can be developed for each pavement section.

7. To disseminate information on pavement performance models and cost-effectiveness to the highway administration and to the responsible highway engineers, so that optimal methods of treatment can be selected.

8. To determine the feasibility of using a statewide system of pavement condition monitoring sites to characterize the condition of pavements throughout the state.

9. To support and, if appropriate, recommend improvements to the existing pavement management system so that it combines the research findings, the knowledge and experience of the responsible engineers, and the objectives of the Highway Division Administration into a tool that can be used for programming and allocation of available funds for rehabilitation and maintenance.

PROJECT HISTORY

The elements of a pavement condition rating system were first started in 1969, when pavements were subjectively evaluated by recording the amount of cracking, patching, rutting, raveling, and abrasion present in each highway section. These surveys were conducted once every two years. Starting in 1976, the collection of cracking, patching and rutting data was discontinued in favor of a system which ranked pavement sections into one of five possible categories ranging from "very good" to "very poor". These biennial surveys have continued until the present. The results have been included in the Pavement Management Report (Formerly, the State Highway System Preservation Report).

A proposal for the research and development of a statewide pavement management system was first presented in 1976. The goal of this proposal was to determine if a pavement could be rated by repeated deflection testing at specific sites. The proposal was approved and included in the annual highway research work program in 1977, and the first full year of funding occurred in 1978. In August, 1979, an automated Dynaflect deflection testing system was purchased and placed in operation. A system of pavement deflection monitoring sites was selected from sample sites selected for the Highway Performance Monitoring System (HPMS). During 1980, over 400 sites were tested, and an additional 500 sites were tested in 1981. Since that time, these original sites have been tested once every two years and additional sites have been added. At the end of CY 1984, there were over 56,000 data points available for analysis.

In August, 1981, the State Highway Engineer appointed a Pavement Management Task Force to evaluate all activities within the Highway Division that might contribute in some way to pavement management. One Task Force assignment was to determine if data that was being gathered for other purposes could be used in pavement management. Other charges to the group were: (1) determine the type and detail of data that should be collected; (2) recommend an organizational structure for a pavement management system for Oregon; (3) determine the appropriate funding level; and (4) advise how the system should be used.

At this time the responsibilities of the Pavement Management Research Study were divided between the Highway Division Research Section and the Planning Section. The Planning Section was charged with the development, testing, and implementation of a prototype pavement management system. The goal, at that time, was to use computerized pavement condition data as well as other highway statistical data to produce a computer generated list of prospective surface preservation projects in priority order. The Research Section was charged with conducting further research into the use of non-destructive testing data and other pavement condition data to predict remaining useful pavement life, and to determine the most cost-effective methods of surface preservation throughout the pavement life.

PROJECT HISTORY (Cont.)

In 1982, the Planning Section developed and implemented a computerized Pavement Management System Index (PMSI) based on the District Maintenance Supervisor's pavement condition ratings, surface roughness, skid resistance, traffic coefficient (loadings), volume, and safety rating. This system was viewed as the prototype for the final pavement management system.

At the same time the Planning Section was working on the pavement management system, the Research Section was collecting and processing nondestructive test data, including deflections, surface roughness, and skid resistance.

A program was implemented in July, 1983 to track maintenance costs on three highway segments in each of the 82 maintenance sections in the state so that maintenance costs could be correlated with pavement condition. The segments were selected by the Research Section from recommendations provided by the District Maintenance Supervisors. The cost tracking is incorporated into the Maintenance Management System to make the record keeping and information retrieval relatively easy. New deflection test sites were established on a number of these segments and pavement condition data is currently being collected on these sites.

In June, 1984, the research project was expanded to include a study of the effectiveness of various surface preservation treatments that would be constructed under the State Special Surface Preservation funding program. New pavement test sites were established and monitored before and after construction was performed, and monitoring will continue until the end of the treatment life is reached.

At the present time, Pavement Condition Ratings (PCR) use a "knowledge based expert" system that combines visual assessment of levels of distress in the pavement with "expert" opinion on the pavement condition, history, and future needs. This data, combined with the traffic loadings, is then incorporated into a Pavement Management System Index. This index is used to monitor the state of the system as well as develop candidate sections for future action.

PROJECT FINDINGS

1. Literature Review

The initial review of available literature revealed a wealth of information regarding the development of a pavement management system, and the use of objective pavement monitoring data in such a system (see References 2 - 14.)

Of the states that have implemented a pavement management system, a number have systems that are based on the use of visual condition survey data and subjective opinions about rehabilitation needs. In some states, road roughness is used to supplement the ranking developed by visual condition surveys. A few states have also attempted to use statewide deflection monitoring data in their pavement management system, but have abandoned such attempts due to the level of effort required and the accompanying high cost involved.

Rideability is considered, by some, to be the most cost effective and useful type of objective measurement data. However, rideability, in general, addresses only one of several concerns.

At the beginning of this project, literature supported the concept that deflection measurements could be used as an objective criteria in a system-wide inventory of pavement rehabilitation needs. Also, it was thought that deflection measurements could provide the most cost-effective means of evaluating pavement strength for designing new pavements and overlays.

The most popular method of deflection measurement has been the Dynaflect trailer. This device simultaneously measures pavement deflection at several locations within the deflection basin, through the application of a sinusoidally varying load to the pavement surface, and detecting pavement deflection at the point of loading and at one-foot intervals away from the load. Some states own several units and use them for pavement design and performance testing. For many, the Dynaflect has replaced the use of the Benkelman beam for deflection measurements, since it was believed to produce more consistent and precise results. Some states indicate that the Dynaflect is cheaper and faster to operate than the Benkelman beam; however, this opinion is not shared universally.

PROJECT FINDINGS

1. Literature Review -Cont.

The falling weight deflectometer, a relatively new device in the deflection measurement field, is rapidly gaining in popularity. This device measures deflections at several locations within the deflection basin, but it has the added advantage of being able to measure the deflections for several different load levels, including levels that equal or exceed those of a standard 18 kip equivalent axle load. Several surveys of deflection measuring devices identify the falling weight deflectometer as producing pavement deflections most nearly equal to those produced by moving loads. Because the unit can test pavements at several different load levels, it can be used to estimate base and subgrade moduli directly, greatly facilitating the use of mechanistic pavement models for pavement design.

More recently, some agencies are developing 'knowledge-based expert systems' for pavement management. These systems draw on the accumulated knowledge of organizations and individuals to make decisions based on various factors. The use of 'Delphian Techniques' to quantify any bias in 'expert opinion' should allow objective conclusions from this type of system. These systems are usually computer based.

Other agencies, FHWA included, are investigating automated methods of gathering and analyzing pavement distress data. At present, cracking, rutting, and rideability are the predominate distress symptoms being measured with these systems. Development of the analysis programs for these operations is still in the early stage.

New, more powerful, methods of statistical analysis are now available. The Statistical Analysis System (SAS) package gives the option of more sophisticated analysis of data than was possible even five years ago. The Multivariate Analysis procedure on SAS has been used with some success and promises more in the future.

The literature review indicates on-going concern for pavement management and a possible trend toward 'expert systems'. The use of more powerful analysis tools will probably contribute more to the present knowledge in this area.

PROJECT FINDINGS

2.1 Data Collection - General

At least 3 sets of Dynaflect readings were taken on the 1100 Highway Performance Monitoring System (HPMS) sites on State highways. this was accomplished over a period of 7 years. The data from these sites were to provide the basis for future performance models.

2.2 Data Collection - Seasonal

Sixteen sites were selected for monthly testing to develop 'seasonal' correction factors. These factors would be used to normalize the readings for the other sites. Then valid comparisons could be made with data taken under different conditions at the same, or other sites.

Due to construction and maintenance activity, the surface and base at four of these sites were altered substantially. Data was still collected at these sites but was not included in the statistical analysis of seasonal trends. The remaining 12 sites yielded the 1591 sets of readings used in the statistical model.

3. Data Organization and Storage

The following data were collected for each set of deflection readings: air and pavement temperatures, percent of cracking and patching, depth of rutting, time and date, and the five Dynaflect geophone readings.

Surfacing, base, and subgrade information was collected from plans and laboratory reports provided by Materials Section and the Surfacing Design Unit of the Highway Division. This data included historical information on previous bases and pavements at the site.

Weather data was added from the National Oceanic and Atmospheric Administration (NOAA) annual daily weather observations file. This data is in the form of daily observations at 223 stations throughout the state. Representative stations were selected for each 'seasonal' site on the basis of geography, altitude and proximity to the site.

All of the above information was integrated into a single computer file containing all field, weather, and construction data prior to analysis. This integration was accomplished in a series of steps in order that changes in data, data transforms, or other preanalysis functions could be done without modifying large sections of the computer database or the programs used to analyze the data.

Skid and Rideability information is now kept in discrete test form on other files. This is because these data are used by others within the Division. They can be, and are, integrated with the deflection data for analysis purposes.

4. Data Analysis

Analysis of the data was done using the Statistical Analysis System (SAS) program on the ODOT IBM Model 370/3090-200 mainframe computer. The SAS General Linear Models (GLM) procedure with the multivariate analysis (MANOVA) option (15,16) was used for generating and testing the model. This program has the ability to produce highly complex statistical models and process large amounts of data.

North Dakota (14) had used this technique with success. The results of this analysis agreed with North Dakota in many areas. The areas of agreement and difference are noted.

Although multivariate analysis was used for the overall model, It was apparent that some of the variables had relationships that were not linear (Their equations were not straight lines.). The SAS stepwise regression (REG) procedure was used to evaluate these variables and develop functions that represent these non-linear variables as linear before adding them to the model (17).

Tables A2 and A3 of Appendix A show the results of this analysis.

The significant variables were:

Effective Depth - The original surfacing depth less rutting, if any. This variable was significant for all geophones except #2. This is consistent with the North Dakota model (14).

Crushed Base Equivalent - The base course depth (if treated, then 1.8 x base depth) is significant for all geophones. This is also consistent with the North Dakota model (14).

Treated Base - Although this is a dummy variable (Either a '1' for the presence of base treatment or a '0' if no treatment.), the significance of base treatments appears to be greater than just the calculated increase in CBE. The significance of the coefficients would indicate that the factors used to develop the CBE equivalent for treated bases are somewhat conservative. The presence of treatment would appear to stiffen the pavement structure.

Temperature - The pavement temperature has a relatively consistent effect over the first 2 geophones. Although Rohlf and Rogness (14) used the air temperature in conjunction with the surface temperature, this was not found to be significant. The Oregon method of cutting a hole in the pavement to obtain the internal temperature of the surfacing layer was significant. The effect of this coefficient is consistent with idea that warm asphalts are more flexible than cold.

PROJECT FINDINGS

4. Data Analysis Cont.

Axle Loads - This variable has a significant effect on all geophone deflections. The magnitude of this coefficient is consistent with the theory that pavement fatigue is directly related to accumulated axle loads. The plot of this function (Fig. 1) indicates a stiffening of the structure, as a whole, during the early life of a pavement. This may be due to dynamic compaction or densification of the all pavement layers. Then the deflection tends to increase as the pavement accumulates more ESALs.

No seasonal variation was detected in the deflection readings, once temperature correction was applied (Appendix 'A'). Temperature appears to have a greater effect on surface layer deflections. The seasonal variation was not detectable in the areas commonly associated with the subgrade and base layers.

When the subgrade characteristics (Pass #10, Liquid Limit, etc.) were considered, deflection had a positive correlation with pavement depth. This may be due to the fact that Oregon uses thicker surfacing sections over weaker soils in the design procedure. While the total pavement system is thicker, the total deflection is still higher than a pavement over less deflective soils.

5. Prediction of Pavement Deterioration

With the exception of new pavements, and most PCC pavements, the present AC pavements are a composite of the surfaces that were in place before the latest treatment. Therefore, each individual pavement, to an extent, is unique in one or more ways and exhibits a high variability in measured data.

AXLE LOADINGS - At the Network and Project level, axle loadings were possibly the most important factor in pavement life. However, due to the variability discussed above, accurate estimates of deterioration based on axle loadings alone are still difficult to obtain.

VISUAL DISTRESS - At the Network level, visual distress combined with axle loadings can provide a limited evaluation of pavement deterioration. Used alone, visual distress can be of value for maintenance and project design.

ROUGHNESS - While many consider this to be an indicator of pavement quality, it was not possible to relate this factor to any indicator of the structural quality of a pavement. Generally, a significant deterioration in pavement roughness occurs after deterioration of the structural quality.

PROJECT FINDINGS

6. Life-cycle costs and Effectiveness

The determination of life-cycle values are still under study. The need to follow a pavement or treatment through a complete cycle requires time. The new FHWA Pavement Policy requires life-cycle costs be evaluated.

The design life of Oregon pavement treatments ranges from 3 to 20 years. Studies of the thin surface treatments are under way to determine the effect of this strategy on overall pavement performance.

The Strategic Highway Research Program's (SHRP) Long Term Pavement Performance Study (LTPPS) would monitor pavements for up to 20 years. This project should yield a comprehensive data base that could provide significantly improved adaptive performance models.

Attempts to use maintenance costs to develop life cycle cost were not successful. This was due to the nature of the present maintenance cost tracking system in Oregon. It was extremely difficult to obtain accurate data over any lenght of time.

At the project level, the design procedure uses a target pavement life based on structural factors. This prediction should be as valid as the parameters used in the design process. It appears that a number of Oregon pavements are failing for reasons other than structural (ie. problems in construction and uncommon weather conditions).

7. Dissemination of Information

The information from this research was sent to the Planning Pavement Management Unit, Surfacing Design Unit, and other interested parties. The principle investigator served as staff to the Pavement Management Steering Committee. Results of the analysis were also incorporated in other related research.

PROJECT FINDINGS

8. Development of State-wide Monitoring Sites.

Due to the high degree of variability in pavement structures, it would appear that the development of representative pavement deflection sites for system pavement types is not a cost effective strategy. The reliability of the predictions would be questionable. The present pavement deflection program covering the HPMS sites costs approximately $50,000 - $60,000 per year. While this system seems to correlate with the Planning's Present Condition Rating (PCR) it does not represent the total highway system. By comparison, the PCR ratings are essentially continuous over the highway system and the data gathering costs are significantly less ($10,000 +/- per year - Planning Pavement Management Unit).

Future development of such sites may be possible where a number of data elements can be monitored. The advent of fast, cost-effective, devices that can gather numerous data elements simultaneously may make the need for representative sites unnecessary.

9. Development of a Pavement Management System.

A visual surface condition rating (SCR) was initiated for Oregon pavements in 1969 that rated the surface condition by recording cracks, patches, rutting, raveling and abrasion. The SCR was replaced by the PCR rating made by the district maintenance supervisors for highway sections under their jurisdiction in 1976, 1978, 1980, 1982, 1984, and 1986. This change reflected a consensus of a committee whose directive was to determine the best method of assessing pavements.

This PCR rating evaluates pavement with a five point rating from "very good" (5) to "very poor" (1). The PCR rating is based primarily on the supervisor's evaluation of the visible surface distress, but is also influenced by the supervisor's knowledge of the construction and maintenance history of the section. Standard photographs and monitoring by headquarters's personnel are used to maintain a level of uniformity between districts.

PROJECT FINDINGS

9. Development of a Pavement Management System (Cont.)

The Task Force studied short-term management systems that could be implemented with existing data. It also considered the long-term need to develop a system that can optimize the type and timing of maintenance and rehabilitation strategies. This study was expected to contribute significantly to the long-term system and also provide valuable information to the short-term, or project level system by furnishing information on deflections, spreadability, base curvature index, surface curvature index, ride scores, skid numbers and an estimate of overlay thickness needs on projects being considered for rehabilitation. All of the information developed as part of this study was made available to help decision makers assign priorities to project sections already identified as being in need of rehabilitation.

Under the direction of the Task Force, the Planning Section has implemented a pavement management system (**19**). This system produces a Pavement Management System Index (PMSI). The PMSI exposes critical needs by balancing the load on the highway pavement against it's present condition. The load is represented by the design Traffic Coefficient, as used in the pavement design process.

The present pavement management system is being used to aid in estimating needs and allocating funding. The same system, with few modifications, is also being used to meet the needs of some cities and counties in Oregon.

DISCUSSION

Factors in Pavement Life

Pavement Management decisions could be based on many factors: deflection, traffic loadings, cracks and patches, rutting, friction, and rideability. In this study, only deflection and traffic loadings emerged as being significant for the majority of the pavements. Table 1 shows the effect of each factor in each of the areas of pavement management.

DEFLECTION - The analysis of deflection data (Appendix A) indicates that the Equivalent Single Axle Loadings (ESALs) has the most significant effect on the overall change in pavement strength (Fig. 1.). Maximum deflection values correlated well with the present PCR indices indicating that the present methods of assessment of pavement condition are an effective surrogate (Fig. 2.). The nonlinear nature of the relationship tends to give two possible solutions for a given deflection value. Deflection data is also used in the design process.

TRAFFIC LOADINGS - Traffic loadings on a pavement are probably the best indicator of pavement life, given loading's large effect on the change in pavement strength and the corresponding use of loading in the design process. ESALs are included in the present pavement management system in the form of Traffic Coefficients (TCs) which are also used in the pavement design process. The non-linear relationship between axle loads and deflection makes interpretation of limited data difficult.

RIDEABILITY - Many states as well as the FHWA have proffered rideability as a basis for pavement management. In Oregon, 95% of the pavements are classed as average or smooth, using the FHWA standards (Fig. 3).

In Figure 4 a relationship between PCR values and rideability is charted. It should be noted that, in certain ranges, a given ride number can be related to 3 possible PCR values.

Rideability is a factor in maintenance of pavements. The various maintenance strategies have significant effects on the rideability. Rideability does not appear to relate well to structural condition. Consider the following example: On I-5 in the Tigard area, the ride values (Mays inches) on a new Continuous Reinforced Concrete Pavement (CRCP) average around 100 +/-; while on I-84 in the Pendleton area, an 18 year old pavement, has a ride value in the mid 40's. This points out the high degree of variability in the ride of pavements versus the actual structural condition of the pavement (Fig 5).

DISCUSSION

Factors in Pavement Life

CRACKS and PATCHES - Cracking and Patching did not appear to be significant factors in pavement strength. These factors appear to be significant only at the end of pavement life when failure is imminent. These factors can be significant when combined with the other measures of strength, pavement distress, and loading. Cracks appear to be significant in the maintenance area of pavement management and correlate reasonably well with total pavement loads.

RUTTING - Rutting, when not excessive, does not measurably affect the pavement serviceability. Average rutting can be addressed by low-cost maintenance work such as grinding or area patching. When excessive rutting is encountered, thin overlays may be indicated due to loss of section.

FRICTION - Pavement friction values are a factor in short-term maintenance decisions but, do not measurably affect long-term pavement life. Friction values can be restored by many, relatively low cost maintenance treatments such as grinding, chip seals, and overlays. Pavement friction can be considered a serviceability factor for chip seals because chip loss or bleeding would show up in a low friction value.

Table 1. - EFFECT OF PAVEMENT FACTORS IN PAVEMENT MANAGEMENT AREAS

PAVEMENT FACTOR	LONG RANGE	MEDIUM RANGE	SHORT RANGE	MAINTENANCE OPERATION	DESIGN PROCESS
DEFLECTION	L	L	L	L	H
LOADING (ESAL)	H	H	H	M	H
CRACKING	L	L	M	H	M
PATCHING	L	M	H	H	L
RUTTING	L	M	H	H	M
FRICTION	L	L	M	H	L
RIDEABILITY	L	L	L	H	L

L = Low effect. M = Medium effect. H = High effect.

CONCLUSIONS

The Dynaflect deflection device does not, by itself, meet the needs for pavement management data. The pulse energy from a Dynaflect is not sufficient to disturb the heavier pavement sections.

The sole reliance on single pavement data elements as a basis for pavement management, outside the maintenance or short-term areas, does not appear to be warranted in Oregon.

It would appear that early failure of many pavements in Oregon is due to factors other than those related purely to strength. This leads to the conclusion that, although the pavement design process is valid, factors that cannot easily be quantified may be significant in the overall pavement management process.

The present network level pavement management system in Oregon appears to provide the needed analysis in a cost efficient manner. It either directly, or indirectly, includes many of the factors in pavement life. While it may be possible to construct a pavement management model using more "objective" methods of predicting pavement life cycle values by combining a number of factors, the additional data gathering costs do not appear to be justified at this time.

At the project level, the design unit is beginning to implement the AASHTO design process on a project-by-project basis. The use of 'objective' data elements is very important in this process and is cost effective on a project basis.

FUTURE DIRECTIONS

In the future, pavement management research projects should have a focus narrow enough to produce good, reasonably obtainable, near-term, results without ignoring the total scope of the subject.

At the network level, further work in quantification of elements that are considered to be 'subjective' is needed. This may be possible when the 'all-in-one' data collection systems become cost effective. The feedback from project to network levels is critical to the future success of Pavement Management in Oregon.

At the project level, follow-up analysis of the data gathered under this project should be able to assist in developing improved performance models. Once again, the improvement of data gathering technology could make project level data gathering more cost effective.

Figure # 1 - PLOT OF DYNAMIC MAXIMUM DEFLECTION (DMD) VS ACCUMULATED 18 kip AXLE LOADS (938 Sites Represented)

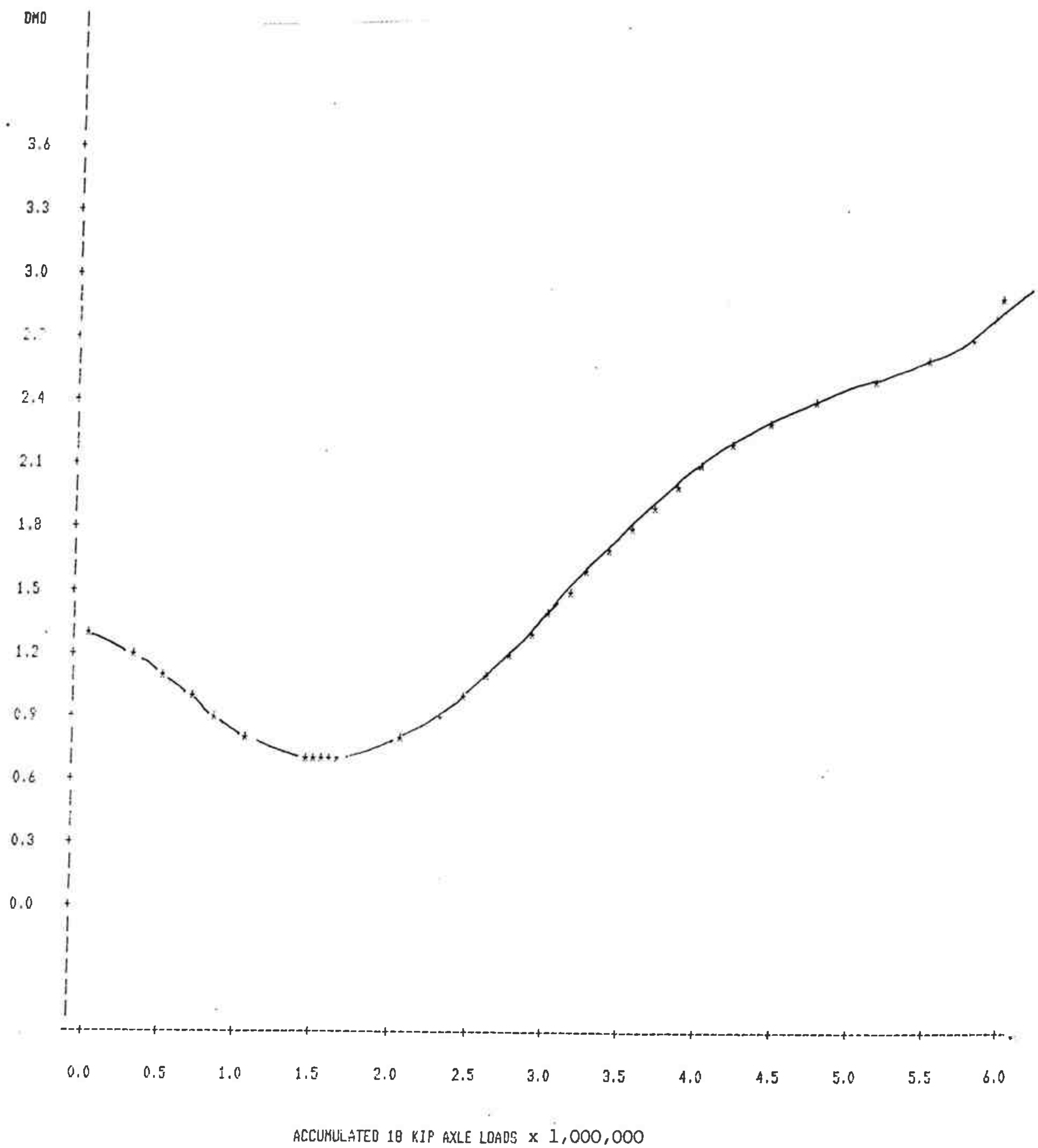


Figure # 2 - PLOT OF DYNAMIC MAXIMUM DEFLECTION (DMD) VS OREGON PAVEMENT CONDITION RATINGS (PCR) (940 Sites Represented)

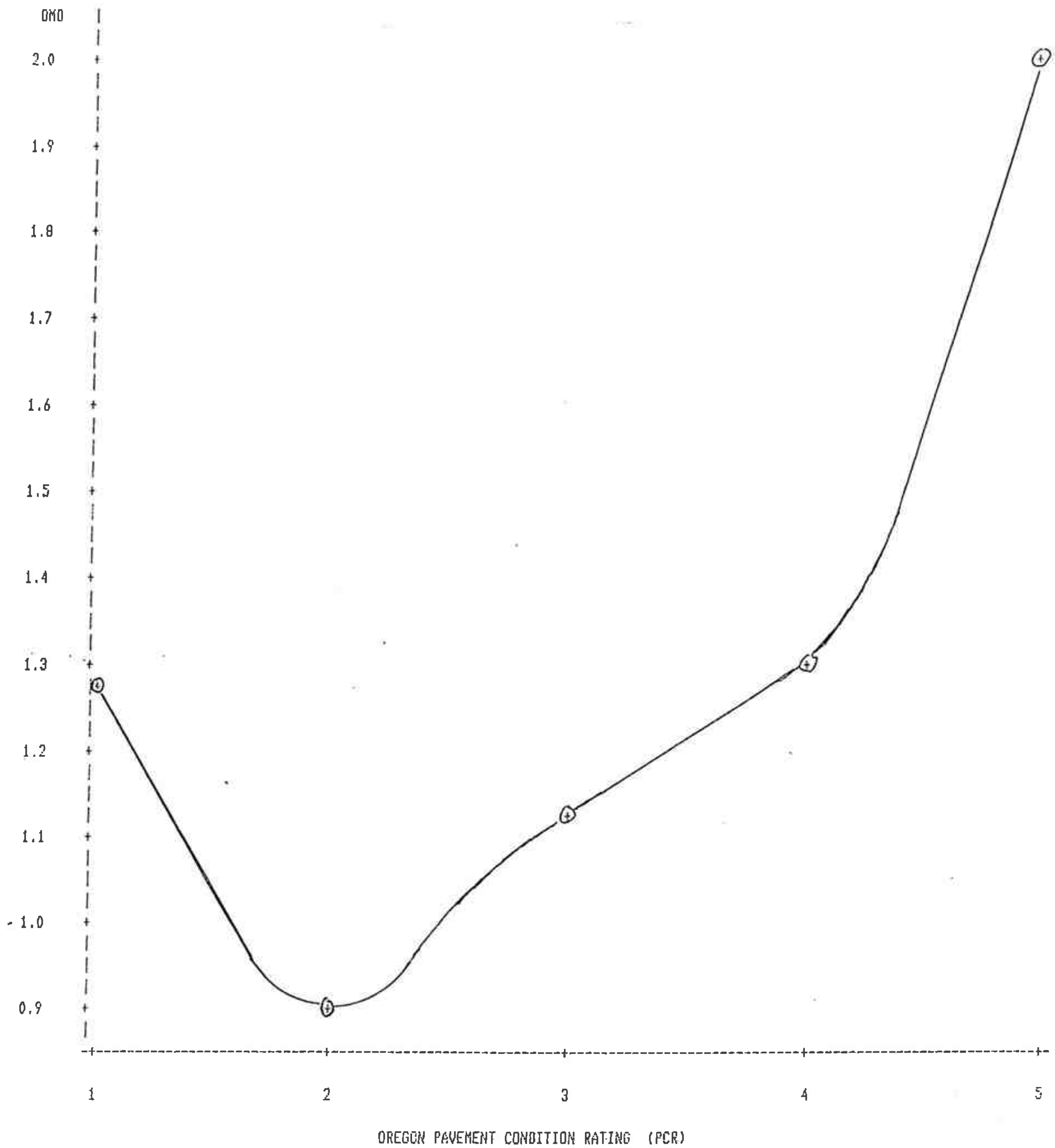
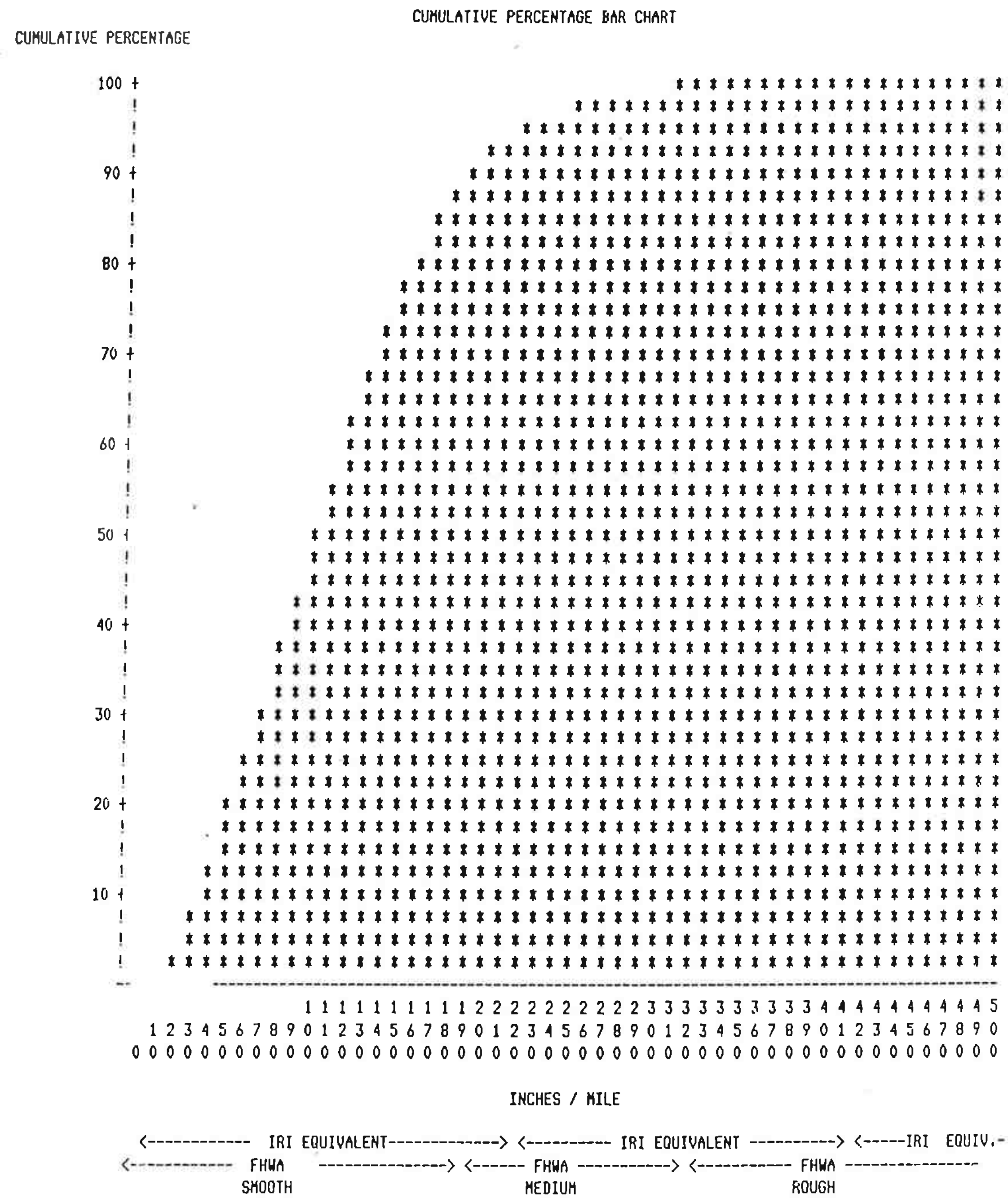


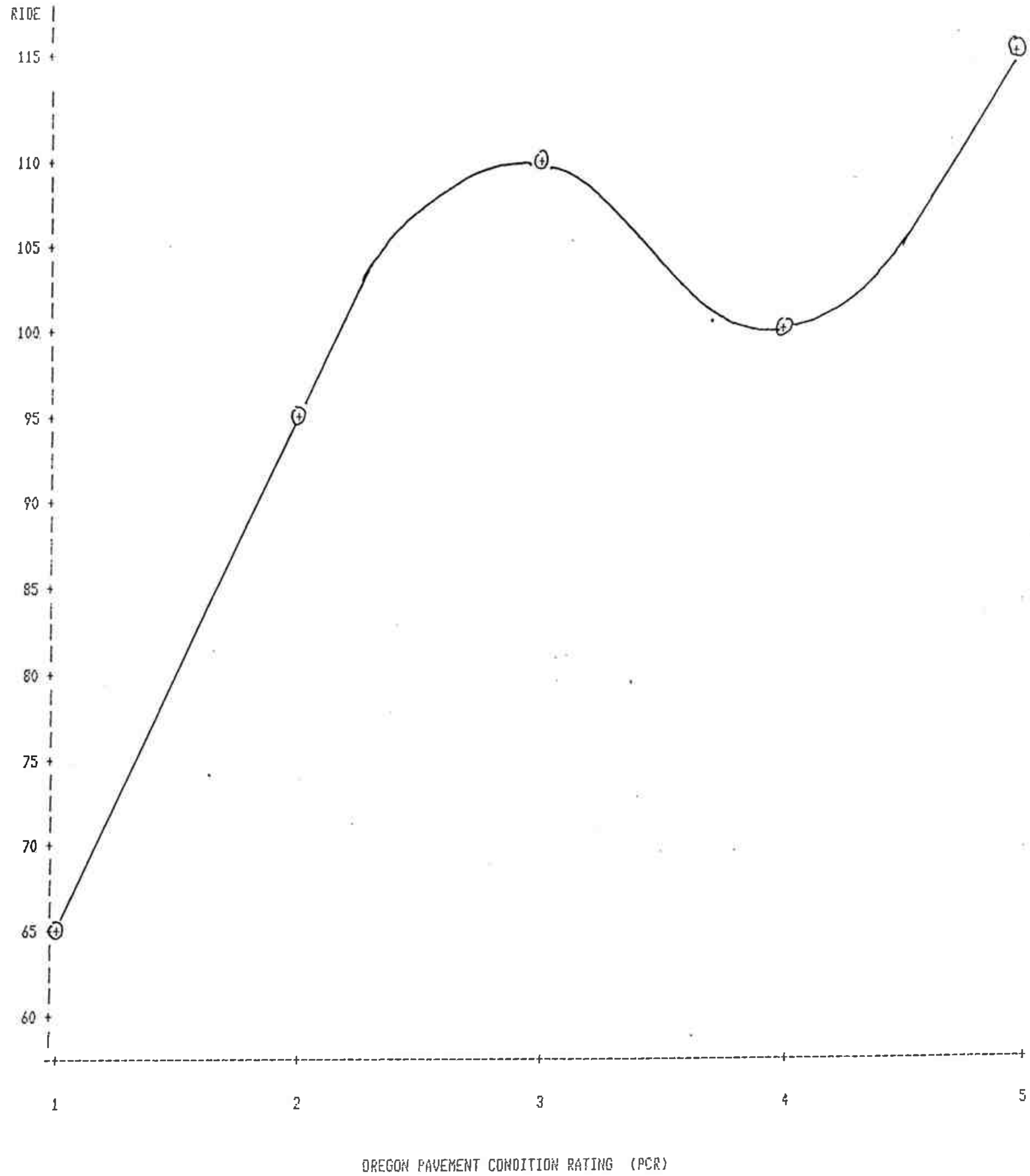
Figure # 3 - DISTRIBUTION OF RIDE VALUES FOR 1985



STATISTICS FOR PAVEMENT RIDE VALUES FOR 1985

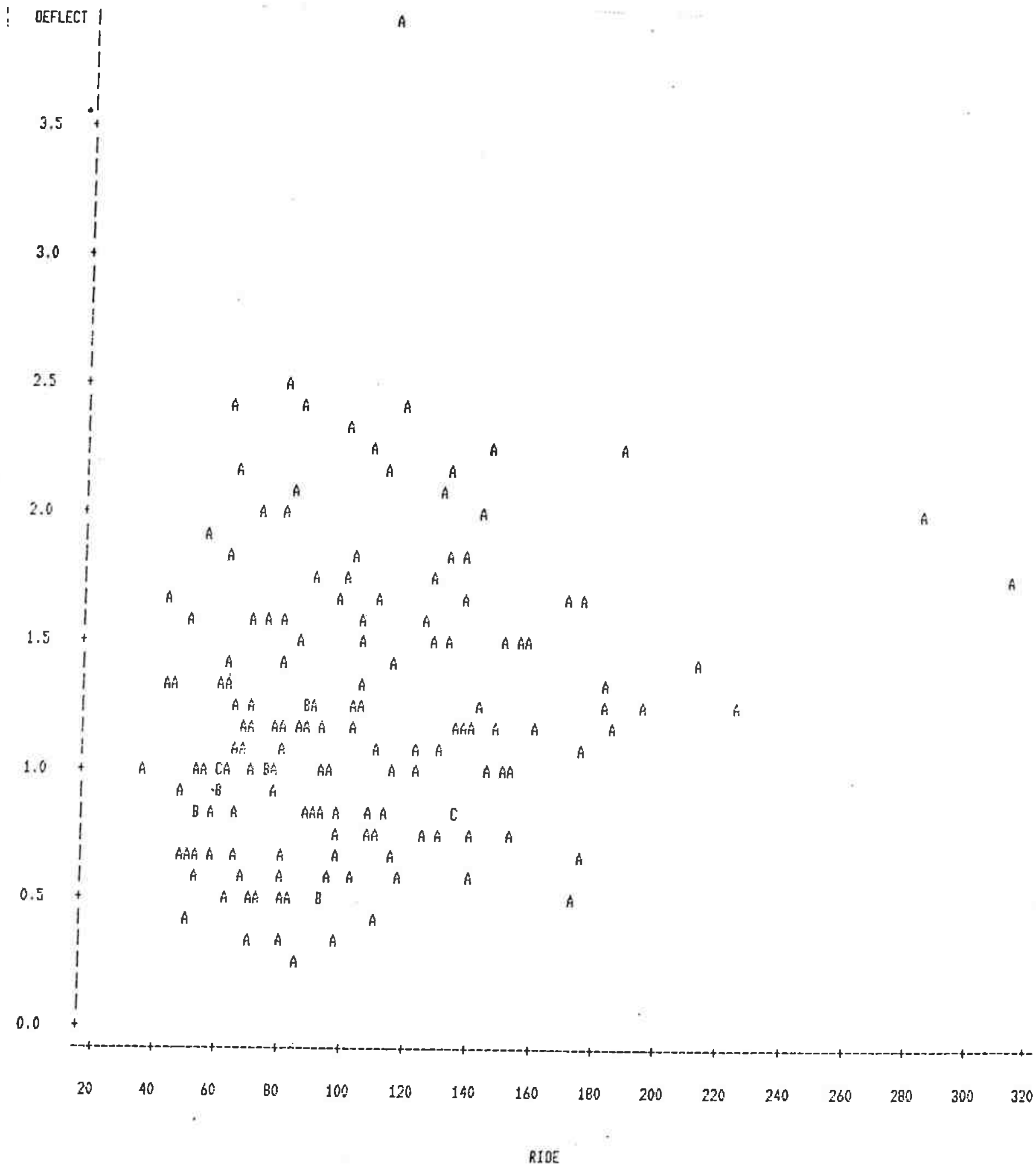
VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN	SUM	VARIANCE	C.V
IN / MILE	47606	114.82	65.85	0.30	498.40	0.30	5466381.44	4337.15	57.35

Figure # 4 - PLOT OF RIDE (MAYS INCHES/MILE) VS OREGON PAVEMENT CONDITION RATING (PCR) (940 Sites Represented)



NOTE: 155 OBS HIDDEN

Figure # 5 - PLOT OF DYNAMIC MAXIMUM DEFLECTION (DMD) VS RIDE (MAYS INCHES/MILE)
(938 Sites Represented)



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ANALYSIS of PAVEMENT DEFLECTION DATA

DATA COLLECTION

Dynaflect deflections have been measured on 1100 Highway Project Monitoring System (HPMS) site on State highways (Figure A1.). These sites may provide the basis for future strength/life-cycle investigation.

Sixteen sites (Figure A2.) were selected for monthly testing to develop 'seasonal' correction factors that would be used to normalize the readings so that comparisons could be drawn between reading that were taken under different conditions at the same, or other sites.

Due to construction and maintenance activity, the surface and base at four of these site were altered substantially. Data was still collected at these sites but was not included in the statistical analysis. It is planned to use these four sites to validate the final model. The remaining 12 sites yielded the 1591 sets of readings used in the statistical model.

The following data were collected for each set of deflection readings: air and pavement temperatures, percent of cracking and patching, depth of rutting, time and date, and the five Dynaflect geophone readings (G1 through G5).

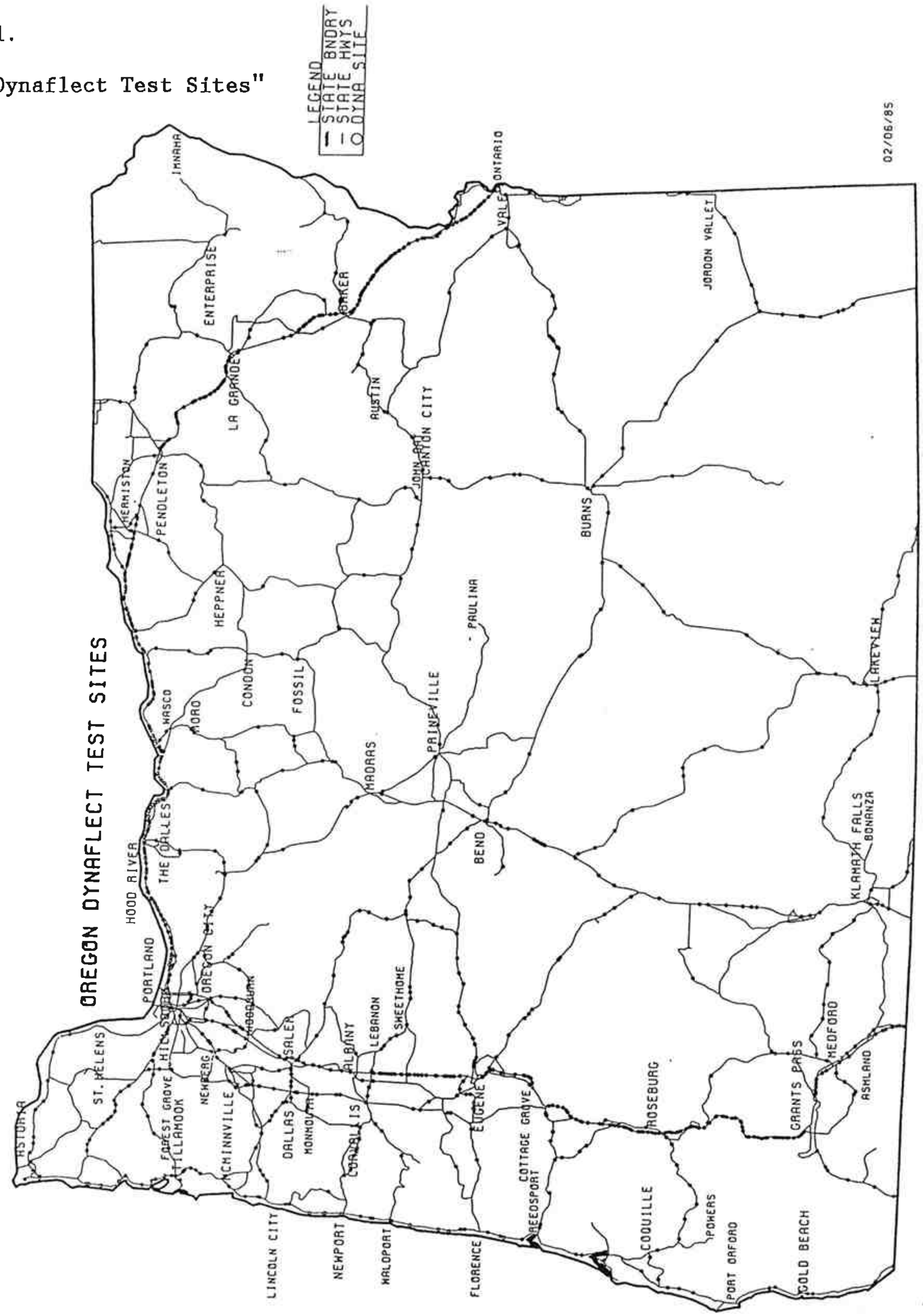
Surfacing, base, and subgrade information was collected from plans and laboratory reports provided by Materials Section and the Surfacing Design Unit of the Highway Division. This data included historical information on previous bases and pavements at the site.

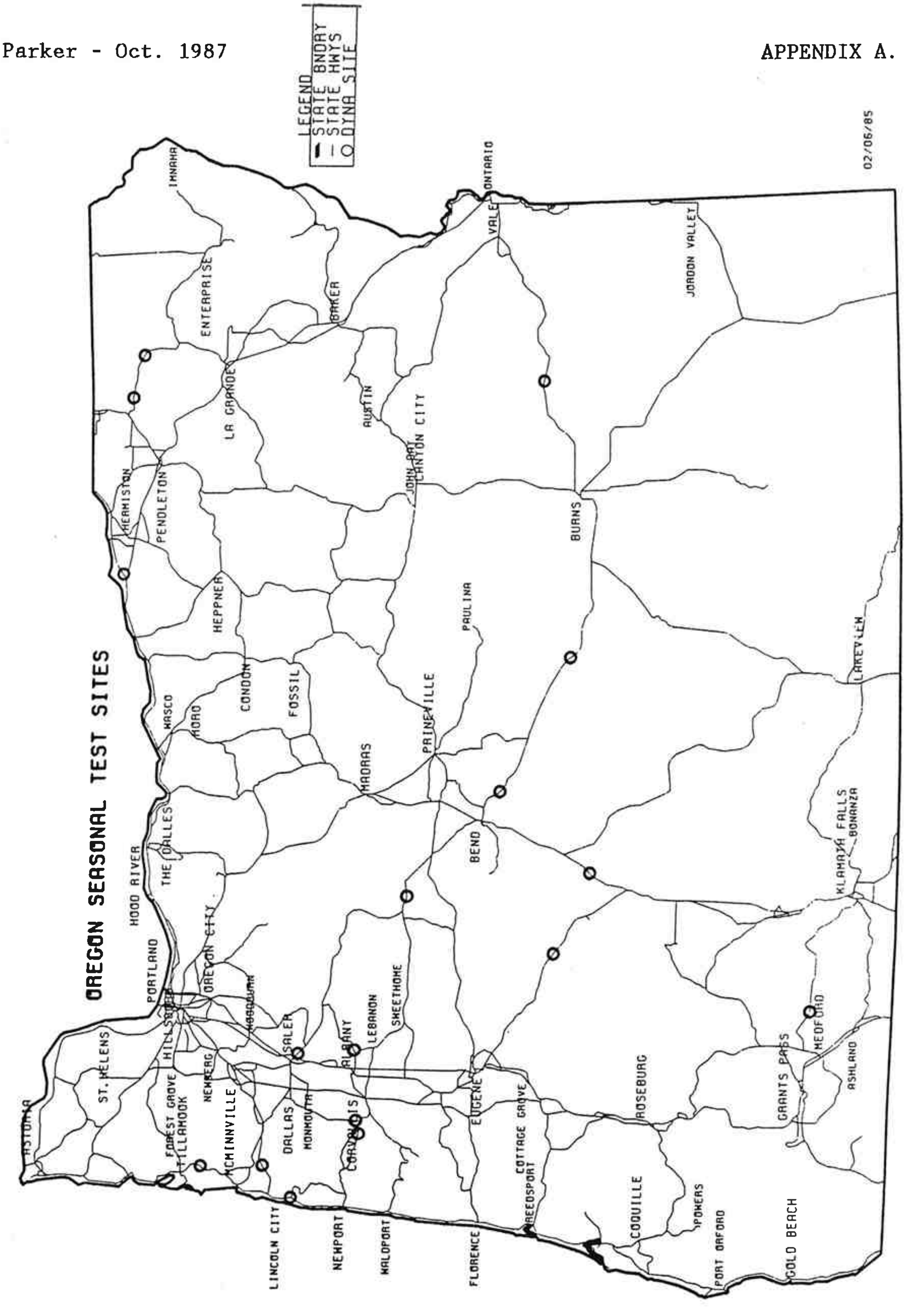
Weather data was added from the National Oceanic and Atmospheric Administration (NOAA) annual daily weather observations file. This data is in the form of daily observations at 223 stations throughout the state. Representative stations were selected for each 'seasonal' site on the basis of geography, altitude and proximity to the site.

All of the above information was integrated into a single computer file containing all field, weather, and construction data prior to analysis. This integration was accomplished in a series of steps in order that changes in data, data transforms, or other preanalysis functions could be done without modifying large sections of the computer programs.

Figure A1.

"Oregon Dynaflect Test Sites"




OREGON SEASONAL TEST SITES
LEGEND
STATE BNDRY
STATE HWYS
DYNA SITE
02/06/85
ASTORIA
ST. HELENS
PORTLAND
HOOD RIVER
THE DALLES
HERMISTON
PENDLETON
IMNAHA
ENTERPRISE
LA GRANDE
BAKER
ONTARIO
VALE
JORDON VALLEY
AUSTIN
JOHN DAY
CANYON CITY
BURNS
PAULINA
HEPPNER
WASCO
MORO
CONDON
FOSSIL
MADRAS
PRINEVILLE
BEND
LAKEVIEW
KLAMATH FALLS
BONANZA
OREGON CITY
WOODBURN
HILLSBORO
FOREST GROVE
TILLAMOOK
NEWBERG
MCMINNVILLE
SALEM
DALLAS
MONMOUTH
ALBANY
LEBANON
SWEETHOME
CORVALLIS
EUGENE
COTTAGE GROVE
REEDSPORT
ROSEBURG
GRANTS PASS
MEDFORD
ASHLAND
LINCOLN CITY
NEWPORT
WALDPORT
FLORENCE
COQUILLE
POWERS
PORT ORFORD
GOLD BEACH

DATA ANALYSIS METHOD SELECTION

Analysis of the data was done using the multivariate analysis techniques outlined by Rohlf and Rogness (14) in their work with North Dakota data.

Multivariate analysis can be used when there is a strong correlation between dependent variables (the geophone readings). The values in Table A1 indicate the correlation between individual geophones. A 1.00 would be a perfect correlation and a 0.00 would indicate no correlation. The degree of correlation between the readings as a whole makes the use of multivariate analysis possible.

TABLE A1. - DYNAFLECT SENSOR CORRELATIONS

	G1	G2	G3	G4	G5
G1	1.000000	0.880794	0.608124	0.363348	0.218581
G2		1.000000	0.852717	0.648261	0.485632
G3			1.000000	0.917517	0.814065
G4				1.000000	0.964432
G5					1.000000

All correlations are significant at the 1% level.

The Statistical Analysis System (SAS) program on the ODOT IBM Model 370/3090-200 mainframe computer was used for the analysis. The SAS General Linear Models (GLM) procedure with the multivariate analysis (MANOVA) option (15,16) was used for generating and testing the model.

Although multivariate analysis was used for the overall model, It was apparent that some of the variables had relationships that were not linear (Their equations were not straight lines.). The SAS stepwise regression (REG) procedure was used to evaluate these variables and develop functions that represent these non-linear variables as linear before adding them to the model (17).

MODEL VARIABLE SELECTION

The statistical model was constructed by starting with all available variables and then checking the significance of each variable's contribution to the model. If a variable did not show significant (10% level) contribution to the overall model, it was discarded. Also the overall fit of the univariate relations was optimized by variable selection.

It was found that, for some of the variables, the nature of the relationship was non-linear. In these cases, a polynomial curve fitting technique was used to determine the nature of each variable. These variables were then defined in terms of the polynomial equation and added to the linear model.

The variables selected were:

EDEEP - The effective depth of the surfacing material. This variable was derived by subtracting the rutting depth from the original surface thickness.

CBE - The crushed base rock equivalent value as used by the Surfacing Design Unit. This variable is calculated by multiplying the depth of treated bases by 1.8 and adding that to the depth of crushed base, if any.

TB - This variable was a dummy variable indicating the presence of a treated (asphalt or portland cement) base. It could not be eliminated by the use of the CBE factors.

TFACT - The pavement temperature (° F.) taken by inserting a thermometer into a hole in the pavement at the time of the test. This variable was non-linear and took the form of:

$$\text{Deflection} = 0.227(T) - 0.00015(T)^2 + 0.0000004(T)^3.$$

ESALADJ This variable was highly complex as it also is a time based variable. The Annual ESAL value was calculated using the Traffic Coefficient value. This annual figure was multiplied by the chronological age of the present surface yielding an accumulated ESAL for the pavement. This value was fitted to the deflection data giving the curve shown in Figure 3. The equation took the form of:

$$\text{Deflection} = K - 4.12(ACAL) + 1.3(ACAL)^2 - 1.48(ACAL)^3$$

$$+ 0.936(\text{Log}_e(ACAL)) + 0.0117(e^{ACAL}) + 0.047(TIME(e^{ESAL}))$$

Where: ACAL = Accumulated Single Axle Loads $/ 10^6$.
ESAL = Equivalent Single Axle Loads $/ 10^6$.

COMMENTS ON VARIABLE SELECTION

It might be noted that some elements appear to be missing in this analysis. The following variables were considered and rejected as having no effect on the model:

WEATHER - Although it was expected that precipitation and air temperature values would have an effect, neither variable was significant in the model. The precipitation was tried for 5 and 10 day periods prior to the test with no significant correlation.

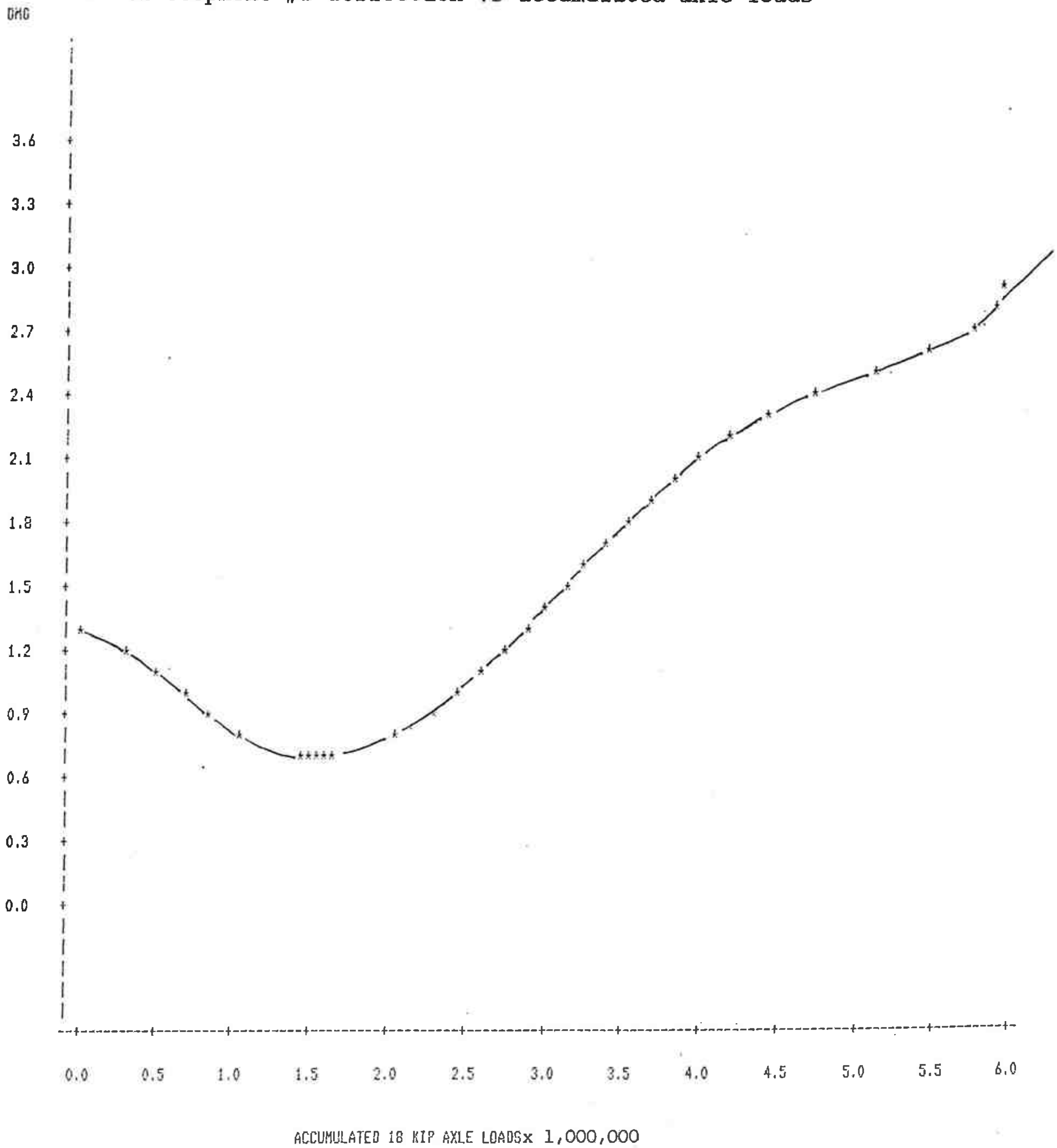
SEASON - It was expected that the season of the year would yield a significant correlation, but none could be found once the temperature correction was applied. It was concluded that there was no detectable 'seasonal' effect.

SOILS - The Pass #200 variable was tried with no effect, particularly after adding the Pass #10 variable. Other researchers have also indicated that the Pass #10 is an effective surrogate for the Pass #200 value.

All the above variables were analyzed using the polynomial fitting processes before they were rejected.

Figure A3

"Plot of Geophone #1 deflection vs accumulated axle loads"



GEOPHONE DEFLECTION MODEL

The multivariate regression model yielded the coefficients and standard error values listed in tables A2 and A3. The values shown in Table A2 indicate the effect of each independent variable on the deflection of each geophone. These coefficients, when multiplied by the value of the variable yield that portion of the geophone deflection attributable to the particular variable.

The R-SQUARE values are an indicator of how much of the variation of readings at each geophone can be explained by the model.

TABLE A2. DYNAFLECT GEOPHONE MODEL COEFFICIENTS

VARIABLE	G1	G2	G3	G4	G5
R-SQUARE	0.63749	0.66235	0.64782	0.58853	0.52255
INTERCEPT	+3.07211*	+2.33209*	+1.72688*	+1.26175*	+1.00036*
EDEEP	-0.05245*	+0.00591	+0.03489*	+0.04754*	+0.05107*
CBE	-0.00628*	-0.00656*	-0.00591*	-0.00432*	-0.00314*
TB(DUMMY)	-0.21358*	-0.04646*	-0.03512*	+0.05373*	+0.05235*
TFACT	+0.65069*	+0.29400*	+0.07927*	-0.01482*	-0.03672
ESALADJ	+0.75073*	+0.67570*	+0.58039*	+0.47887*	+0.41594*

* Denotes significance at the 1% level

TABLE A3. DYNAFLECT GEOPHONE MODEL STANDARD ERRORS OF ESTIMATE

VARIABLE	G1	G2	G3	G4	G5
INTERCEPT	0.05927	0.04210	0.03423	0.03136	0.03119
EDEEP	0.01372	0.00974	0.00792	0.00726	0.00722
CBE	0.00205	0.00146	0.00118	0.00108	0.00108
TB(DUMMY)	0.01417	0.01006	0.00818	0.00750	0.00746
TFACT	0.03576	0.02540	0.02066	0.01892	0.01882
ESALADJ	0.02306	0.01638	0.01332	0.01220	0.01213

Plots were made of the predicted vs actual deflections and for error vs actual deflections. The predicted vs actual showed points clustered about a line with the slope of 1 indicating that the values tended to be equal. The error or residual values vs the actual values showed a random distribution indicating no systematic errors.

GEOPHONE MODEL INTERPRETATION

Before the multivariate model can be interpreted, a review of the general principles governing Dynaflect deflection reading is appropriate. The general layout of the geophones is shown in figure A4.

The five parameters associated with the relation between deflection readings and the strength of pavement structures (14,20) are:

1. DMD - The Dynamic Maximum Deflection is the reading at geophone #1. This value is an indication of the overall structural condition of the pavement system. A high value would indicate low base or surface layer strength or poor subgrade support.

2. SCI - The Surface Curvature Index is the difference between the readings at geophones # 1 and 2. This value relates to the structural properties of the surface layer and the stresses at the bottom of the pavement surface.

3. BCI - The Base Curvature Index is the difference between the readings at geophones #4 and 5. This value is an indication of subgrade support.

4. SPI - The Spreadability Index (or percentage) is calculated as the average of all the geophones divided by the geophone #1 value. This index, while not an indicator of strength, does relate to the pavement stiffness and load-carrying capacity.

5. G5 - The fifth geophone reading is an indicator of the subgrade modulus.

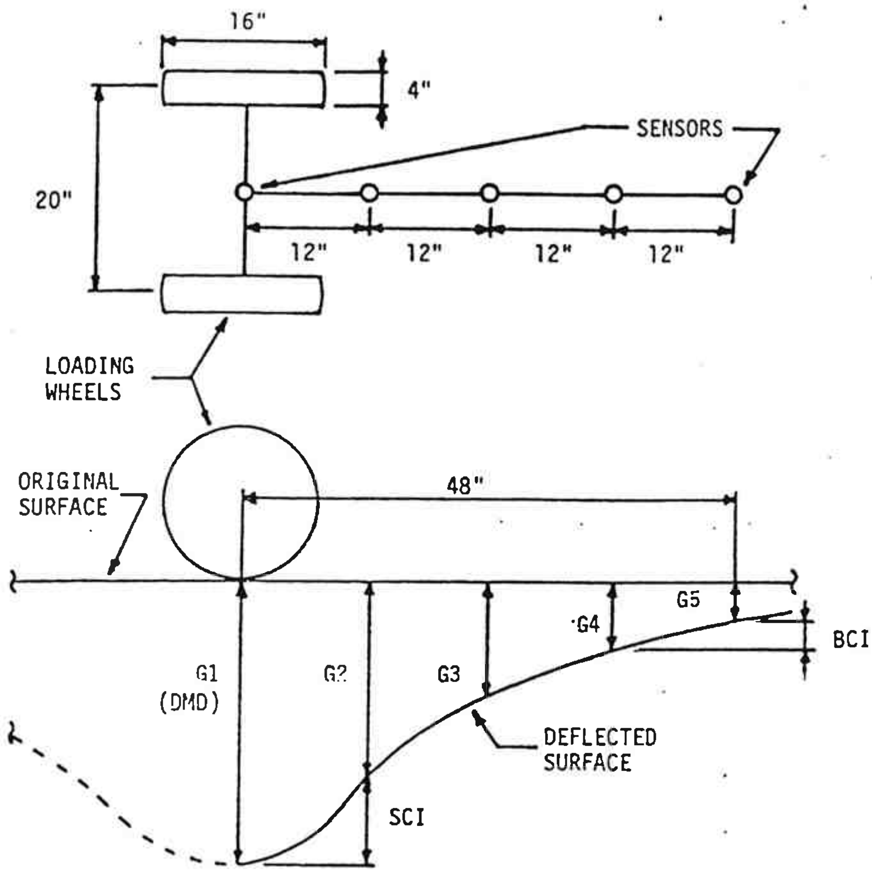
The nature of the above parameters give an idea of the particular pavement attributes associated with each of the individual geophone deflections. Generally, it can be said that the deflection from Geophones 1 and 2 relate most directly to the base and surfacing condition, while geophones 4 and 5 deflections relate most directly to the condition of the subgrade (20).

For the purposes of assessing overall pavement condition and remaining life, it would appear that analysis of the Spreadability Index (SPI) could be an useful tool. The pavement system operates as a single unit, even though there is substantial variability in the individual elements (Subgrade, Base, and Surfacing). As the SPI is a composite of all the readings, it may be said that, to a degree, it represents the condition of the total pavement system.

It should be noted that the model represents only asphalt pavements. Composite asphalt-over-PCC and PCC pavements are not represented.

Figure A4

- Dynaflect deflection basin.



NOTE: Deflections are exaggerated for clarity.

From Rohlf and Rogness (1)

GEOPHONE MODEL INTERPRETATION (Cont.)

EDEEP - This variable's effect is not as great at geophones #1 and #2. This would confirm some of the observations by Rohlf and Rogness (1). The effect of the surfacing thickness appears to be most significant at geophones #4 and #5.

CBE - The Crushed Base Equivalent depth is significant for all geophones #1 and # 2. This would indicate that the base/ surface structure, as a unit, is represented by this reading. This is agrees with the North Dakota model (1).

TB - Although this is a dummy variable (Either a '1' for the presence of base treatment or a '0' if no treatment.), the significance of base treatments appears to be greater than just the calculated increase in CBE. The significance of the coefficients would indicate that the factors used to develop the CBE equivalent for treated bases are somewhat conservative. The negative sign of the coefficient would indicate a stiffening of the pavement structure as a whole.

TFACT - The pavement temperature has a relatively consistent effect over the first 2 geophones. The positive sign of the coefficient is consistent with idea that warm asphalts are more flexible than cold. The sign at geophone #4 and #5 is, as of yet, unexplained.

ESALADJ - This variable has a significant effect on all geophone deflections. The magnitude of this coefficient is consistent with the theory that pavement fatigue is directly related to accumulated axle loads. The plot of this function (Fig. 3.) indicates a stiffening of the structure, as a whole, during the early life of a pavement. This may be due to dynamic compaction or densification of the all pavement layers. Then the deflection tends to increase as the pavement accumulates more ESALs.

The variation in the slope of the curve as the pavement ages further appears to be effect of several types of failure mechanisms within the pavement structure along with increased maintenance patching effort.

The general shape of the curve would imply that the pavement aging process is somewhat similar to a long-term compaction process where the material is compacted to a maximum density by applied traffic loads. Once maximum density is achieved, further applied loads serve only to develop shear or plastic deformation forces within the pavement.

GEOPHONE MODEL INTERPRETATION (Cont.)

Average precipitation values for 5 and 10 days had a low significance for all geophones. At geophone #5, this would indicate that the subgrade condition may be more dependent on the nature of the materials than on transient moisture. The average moisture content of the subgrade may have a greater effect and be less variable. The LL, PI, P10, and P200 data may be more significant as they relate directly to the performance of soils under varying moisture conditions.

Seasonal variations were not noted in any of the test sections after correcting the values for temperature. It was expected that there would be some seasonal variation, but none were detected.

It might be noted that when the axle loading factor was added to the model, the cracking and patching factors were no longer significant. The relationship between these variables was explored further to determine if a relation existed between accumulated axle loads and the cracking and patching percentages. Analysis failed to find any significant correlation between cracking, patching, and the ESAL data.

Generally, this model can be said to represent most of the known sources of variation in deflection of a pavement system. The model addresses the surface, base composition, subgrade quality, and transient weather effects.

TEMPERATURE CORRECTION EQUATIONS

Using a standard temperature of 70° F., the temperature adjustment equations are:

$$G1_a = G1 - (G1 \times (0.227(T) - 0.00015(T^2) + 0.0000004(T^3) - 1)$$

$$G2_a = G2 - (G2 \times (0.227(T) - 0.00015(T^2) + 0.0000004(T^3) - 1)$$

Where: $G1_a$ = Temperature adjusted value for geophone #1.

$G2_a$ = Temperature adjusted value for geophone #2.

T = Pavement temperature in degrees F.

It should be noted that only Geophones # 1 and 2 are being adjusted for temperature. This is because, in the general model, the effect for temperature is low and somewhat less significant for the other geophones.

Previously, a set of temperature correction factors was developed by Highway Research Section to standardize geophone readings to a 70° F. standard. This correction was tested against the model and it was found that it was more valid for geophones 3, 4, and 5 at a lower significance level than the coefficients in Table A2. The correlation for geophones 1 and 2 were significantly less that those in the model. This is probably the result of using limited numbers of sites in the development of the previous temperature correlations. The corrections developed would probably be adequate for comparison of readings taken at a single site, but would not be adequate for comparison of readings from different sites. It is recommended that these previous corrections not be used.