

HIGH-SPEED ROAD PROFILE EQUIPMENT EVALUATION

by

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A Feasibility Study for High-Speed Road Profilometer
Equipment

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PREFACE

This is the first in a series of reports which will be written covering the findings of this research project. This report is intended to define the problem and discuss preliminary considerations. It also evaluates the capabilities of available equipment.

Future reports are planned which will more completely describe the data handling problems involved in this project and the application of these techniques to any equipment obtained by the sponsors. One report will be written to evaluate the possible capabilities of a gyro-stabilized platform. A final report is planned to summarize all phases of the project.

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ABSTRACT

The importance of evaluating the relative smoothness of pavements is well recognized in the highway profession. In the past, however, this evaluation has been largely a matter of qualitative judgment. Such evaluations are useful in service-ability-performance studies and in studies of mechanistic evaluation of pavements for structural adequacy. Pavement surveys are used by maintenance engineers, design engineers and highway administrators to make many decisions with reference to the highway system.

This report discusses the parameters affecting the measurement of roughness profiles, the evaluation of these parameters by various techniques, and the importance of measuring these profiles at high speeds. Several types of available equipment are discussed and associated data processing techniques are described. Recommendations are made to the Texas Highway Department with reference to the future development of equipment to serve the purposes of the Department.

INTRODUCTION

Design speeds for highways have increased steadily since the development of the automobile. The high design speeds used for modern highways demand that long flowing ribbons of pavement be maintained in a very smooth condition in order that the traveling public will be served adequately.

Evaluation of the relative smoothness of pavements has in the past been largely a matter of qualitative judgment, but now there is a recognized need for developing equipment which is capable of providing a quantitative measure of pavement smoothness. Such equipment is badly needed in the pavement evaluation studies which are now being conducted in Texas and which are expected to continue for the next several years.

Equipment for measuring pavement roughness which has been developed up to now is limited in the accuracy with which the true road profile can be measured and in the speed with which measurements can be made. In general, the slower equipment gives greater accuracy; however, there exists a need for developing a new device capable of measuring road roughness more accurately and more rapidly than is now possible. Particular attention should be given to long-wave-length roughness (25 feet plus) as these characteristics are not presently being evaluated satisfactorily.

Recent developments in the electronics and directional control instrumentation field may make possible the fulfillment of this need; however, no concerted effort has been made in the past to use these developments for highway pavement surface evaluation. The study, discussed herein, proposes to evaluate the feasibility of utilizing this and other recent technology in the development of high-speed road profile measuring equipment.

PURPOSE OF PAVEMENT EVALUATION

Pavement condition is a subject of concern to highway engineers including designers and maintenance personnel. By far the largest interested group, however, is composed of highway users. Every highway user seems to rate pavement condition either consciously or subconsciously every time he rides in a motor vehicle. There are a great many reasons for evaluating pavement condition, and even more ways of doing it. The names applied to the process are varied and many of the definitions are unclear. Terms like performance, serviceability index, condition survey, sufficiency rating, performance rating, and others are often bantered about by engineers and laymen alike. The definitions of such terms, however, are not precise and differ for the various interested parties.

Philosophy of Pavement Evaluation

Two major categories of evaluation emerge: (1) serviceability-performance studies (functional behavior) and (2) mechanistic evaluation for structural adequacy. Regardless of the method used to make the evaluation, most studies can be listed in one of these two main categories.

In general, the serviceability-performance studies are concerned primarily with the over-all behavior of the pavement, that is, how well it is performing its function as a riding surface for vehicular traffic. By and large this also seems to be the area of major concern to the highway user. Studies made at the AASHO Road Test (Ref 1) have shown that about 95% of the information about the serviceability of a pavement is contributed by

the roughness of the surface profile. That is to say, the correlation coefficients in the present serviceability studies at the Road Test improved only about 5% when cracking and patching was added to the index equation.

The second category, mechanistic evaluation for structural adequacy, is concerned with the evaluation of the load carrying capacity of a small segment of pavement and the mechanics or method of carrying the load. This is an important phase of pavement evaluation but it is not of concern in this report and will not be discussed in detail.

Use of Pavement Roughness and Evaluation

Pavement condition and/or roughness profiles are studied for several reasons. A few of these can be stated from committee records of the HRB Committee D-B5, Pavement Condition Evaluation:

1. To measure acceptability for newly constructed pavements.
2. To assist the maintenance engineer and the highway administrator in the determination of optimum maintenance programs.
3. To aid in the establishment of priority for major maintenance, reconstruction and relocation. The object of this type of survey is to rank various pavement sections in terms of their importance and their current ability to serve traffic.
4. To furnish information needed for sufficiency ratings and needs studies. This involves a comprehensive study of pavement systems within a given area.

5. To assist in the determination of the load carrying capacity of the pavement both as to volume of traffic and loads. (This involves an evaluation of structural adequacy of the pavement structure, climatic effects, materials and drainage).
6. To aid the design engineer in the determination of the degree of success with which his design has met the design criteria and to help him learn causes for failure.
7. To serve as a basis for new concepts and design.

This broad basis for use of pavement roughness information points to the need for better and faster methods of roughness measurement. All equipment in current use for the measurement of highway roughness suffers from severe limitations. Many of these limitations need to be removed.

The evaluation of riding quality is complex, depending on three separate complex systems plus interactions between them, the highway user, the vehicle, and the pavement roughness. Hutchinson (Ref 3) has described the problems associated with analyzing the subjective experience of highway users and deriving an absolute measure of pavement riding quality. These require:

1. The development of a suitable mathematical model to characterize pavement roughness.
2. The development of a suitable mathematical model to describe the suspension characteristics of highway vehicles that may be used along with the roughness model to predict the dynamic responses of vehicles.

3. A quantitative knowledge of the response of humans to motion.

This project is associated primarily with factor (1) but secondarily with (2) and (3) since the information required concerning roughness is dependent on the response of vehicles and humans to the resulting motion.

This emphasizes one important aspect of this study, the need to develop a method of measuring "true profile", meaning the faithful reproduction of the undulation of the pavement with respect to frequency, amplitude, slope and curvature at all points.

No really good method for making such true profiles exists. Without such a method the progress in solving the over-all problem will continue to be slow.

The second important aspect of this project is more pragmatic. Based on existing data (Refs 1, 4 and 7) that evaluation of several different roughness parameters have been found to be highly correlated with riding comfort, a better device for measuring present serviceability is needed. In particular, an accurate device which travels at high speed is required.

The term "true profile" then can refer to an elevation profile, a slope profile or an acceleration profile. Any one of these is a "true profile" in a sense if it is a true representation of the factor it attempts to measure. It should be noted that most people are referring to an elevation profile when they refer to the "true profile". From our point of view, however, an instrument capable of reproducing any of these profiles faithfully could prove to be satisfactory. The desirability of a par-

ticular method depends on the use to which the data is to be put.

Speed Aspects

It should perhaps be emphasized at this point that the high-speed requirement is inherent in this project. It is extremely important that this equipment be capable of traveling at speeds of 30 mph or more. Travel speeds of 45-60 mph are definitely preferable since these speeds are closer to the current operating speeds on our freeways and would result in the least danger for personnel handling the equipment.

PAVEMENT ROUGHNESS

In this paper the term "pavement roughness" will be defined as the distortion of the pavement surface which contributes to an undesirable or uncomfortable ride. In previous studies (Ref 2) Hudson and Scrivner have shown that variations in the surface less than about one half inch in length do not materially affect the riding quality and have been termed texture in lieu of roughness. The evaluation of this relation cannot be made until more is known about true profile, vehicle dynamics, and human response. For purposes of this report, however, the definition above will suffice.

Roughness Parameters

Four roughness factors are of general concern to highway engineers: (a) area roughness of the roadway, (b) transverse variations, (c) longitudinal variations, and (d) horizontal alignment of the roadway. In other words, any function of the roadway which imparts accelerations to the vehicle or to the passenger must be examined. More particularly of interest are those functions which influence the comfort or discomfort of the passenger. There are many previous studies which have shown that longitudinal roughness is probably the major contributing factor to undesirable vehicle forces (Ref 1). The next greatest offender is transverse roughness (e.g., the roll component transmitted to the vehicle). The general curvature of the roadway which imparts yaw component to the vehicle is considered to be the least offensive and one which is normally handled by following good highway alignment practice. Whereas the total road roughness is certainly of importance because of normal variations in transverse vehicle placement, it is generally conceded that seventy percent of the vehicles travel in a well-defined wheel path with their right wheels located 2-1/2 to 3-1/2 feet from the right hand lane line.

From this information we are tempted to conclude that measurements of longitudinal profile in the two respective wheel paths, six feet apart, might provide the best sampling of roadway surface roughness. Furthermore, a comparison between the two wheel paths can provide some measurement of the cross slope or transverse variations which are also important.

Instrumentation developed to date has not been totally adequate to evaluate even a longitudinal line profile of the roadway. However, if such equipment could be developed, it should be merely a matter of duplicating the equipment to provide the comparison between the two wheel paths. On the basis of these assumptions we confine our immediate attention to the development of adequate transducers and data processing equipment for recording a single line profile. This confines the problem to two distinct phases: (1) developing adequate transducers for measuring the roadway profile, and (2) developing adequate recording and data processing equipment which is capable of speedy and accurate data analysis to provide the necessary summary information.

True Profile

In the past a great deal of effort has gone into measurements of pavement profiles. cursory examination of the problem indicates that the profile is probably not the factor of major importance to the driver or passenger. Since there is no force associated with elevation nor with velocity, the height of the passenger above sea level, *i.e.*, his elevation, is of no great importance to him within normal ranges, nor is his vertical velocity or rate of change of elevation important. However, his vertical acceleration or rate of change of velocity (second derivative of elevation) becomes very important to him since it has

a force associated with it which exerts desirable or undesirable pressures on his body and its components.

Other studies have shown that some passengers find undesirable characteristics to be associated with certain frequencies. The exact size and relationship of the effects remain to be studied.

In this regard, the characteristics of a line function, some random function (Fig 1), are of interest. To define this function, in this instance an elevation profile, we are interested in (1) wave length, (2) frequency, (3) surface slope, and (4) amplitude (elevation). On the other hand, some people record slope and plot a so-called slope profile as was done on the AASHO Road Test with the AASHO slope profilometer (Ref 1). Finally, it is possible to record an acceleration profile by recording the analog trace output of a vertical accelerometer as done by the Kentucky Department of Highways (Ref 6).

It seems that a discussion of the various components of an elevation profile will be most useful at this time; it being understood, however, that we may not be most interested in recording an elevation profile in the final analysis.

In order to consider this profile, the extremes which are covered in a roadway are of interest as well as some estimate of accuracy which is felt to be desirable (desirable because we can undoubtedly suffice with less accuracy than specified below if some sort of economic balance can be struck). These calculations attempt to describe the extremes of the parameters which have previously been measured in attempts to describe this profile.

These parameters can be summarized as follows: wave lengths

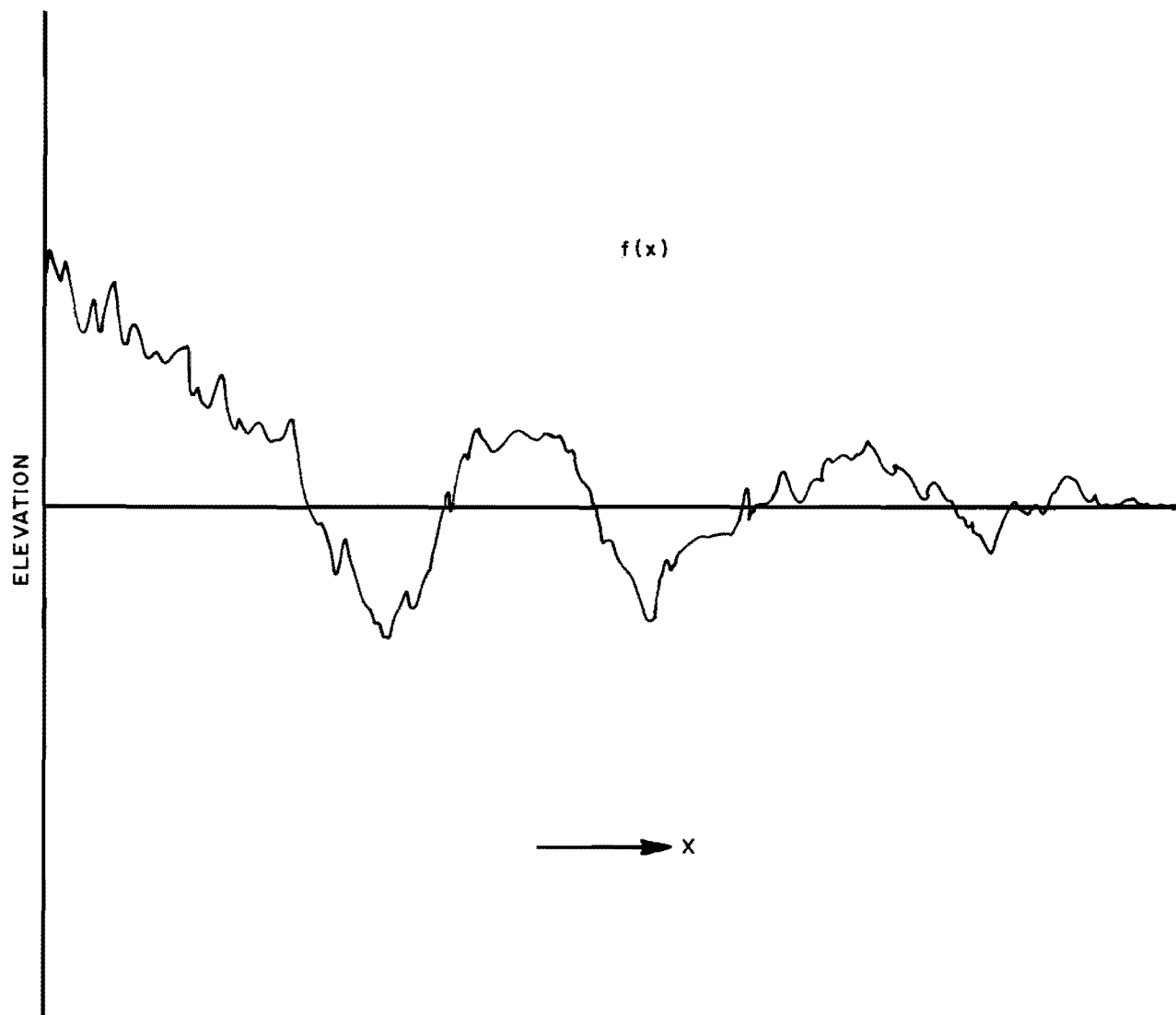


FIGURE 1

Plot of a Random Function

of interest, 0.1 feet minimum, 500 feet maximum; frequency at 60 mph, range .17 cycles per second to 1100 cycles per second, at 40 mph, .1 cycle per second to 700 cycles per second; slope dy/dx or $dy/dt = \pm 18$ degrees.

If a physical set of slope wheels with a finite wheel base of six to nine inches were used, it is probable that an angle of approximately ± 10 degrees or .166 radians, would be all that could be obtained. This would be adequate to do the job.

Amplitudes of interest will depend on ability to measure wave lengths. For short wave length roughness, maximum amplitudes of ± 6 inches will be desirable; however, for wave lengths up to 250 feet, amplitudes of 24 to 36 inches will be desirable. It is impractical to measure such amplitudes directly on an elevation profile. Some compromise is therefore necessary in such cases. As one example of how this is done the GM device attenuates the signal based on frequency and wave length to keep it on an analog chart.

Accuracy

Accuracy is important in addition to the limitations suggested for measuring these parameters. This accuracy is improved by increased resolution in transducers and recording equipment. The values of resolution suggested below should be adequate for evaluating pavement roughness.

Amplitude or Elevation - Accuracy for amplitude or displacement of .010 inches is desirable. This corresponds to .001 radians for a 9-inch wheel base. Using a linear motion transducer covering a range of ± 2 inches this requires a resolution of 400 units or 0.01 inches.

Slope - For slope measurements a resolution of the total range into 100 units should be quite adequate.

Distance - The ability of any piece of equipment to measure distance accurately will decrease with speed. It is highly desirable however to be able to measure distance to the nearest one-half foot at fifty miles per hour.

NOTE: All of the factors discussed herein are relative. The maximums or minimums may not occur together. For example, a 6-inch deflection or elevation change is not of interest associated with a 2-inch wave-length.

PROFILOMETER EQUIPMENT

Equipment capable of fulfilling the objectives of this project can be generally divided into two categories. The first category consists of equipment which produces a summary statistic highly correlated with the present serviceability index of highway pavements. The second category is more sophisticated and consists of equipment capable of measuring a "true profile" of the pavement surface. With proper data recording and processing equipment, the second category of profilometer can also be used to provide the summary statistic. Visual analog profiles, however, are not satisfactory for this purpose.

A survey of existing equipment indicates three devices which purport to evaluate pavement profile at high speeds. These are (1) The Bureau of Public Roads Roughometer, (2) The Kentucky Accelerometer, and (3) The GMR Road Profilometer. Other equipment currently used in the United States must be eliminated because of speed characteristics. These include (1) the AASHO Profilometer, (2) the CHLOE Profilometer, (3) the Michigan-California Profilograph.

An evaluation of the measuring techniques used in the last three instruments indicate that it is not possible to use these principles at high speeds because of the mechanical problem of holding the recording wheel on the pavement at high speeds. The roughometer was also eliminated from consideration. Its speed, while somewhat higher than most other equipment, is still not satisfactory for operation on modern highways. In addition, its ability to measure serviceability of highway pavements consistently over a reasonable period of time is suspect because of temperature and moisture associated variations which were observed at the AASHO Road

Test (Ref 8) and which have been noted by the State of Illinois (Ref 9) with its equipment.

Two new pieces of equipment offer some promise, and some possibility of development within the next two years. These are (1) a gyro-stabilized profilometer which uses a "true horizontal reference" and (2) a summary profiler being developed by Lane-Wells Corporation, Houston, Texas. The gyro-stabilized device offers possibilities of measuring true profile, while the Lane-Wells device is primarily intended as a device for measuring PSI (present serviceability index).

This then gives four types of equipment for primary consideration. Two pieces of the equipment offer possibilities of measuring true profile. The other equipment would be primarily useful for measuring PSI.

Devices for Measuring True Profile

Gyro-stabilized Profilometer - Since 1961 we have been discussing the development of gyro-stabilized profilometers with various manufacturers of gyroscopes. Particular interest has been shown by Sperry Gyroscope Corporation and by Minneapolis-Honeywell Corporation. The latter company at one time proposed to build a device for the Texas Highway Department stabilized by a single vertical gyro. Experience at the AASHO Road Test has shown that a vertical gyro will not provide an accurate reference for measurement of profiles at high speeds. Large errors are introduced into the profile by precession of the gyro due to accelerations imparted by rough roads at high speeds. Further pursuit of this subject with commercial firms indicated that no stabilized platforms of the required accuracy were available at cost of less than \$100,000. A gyro-stabilized platform consists of three gyros mounted with

their principal axes arranged orthogonal to each other to provide three dimensional stability against rotation. Such a platform can be used as a very accurate indication of true horizontal. It appears that development costs for such a device would be approximately \$100,000 if borne by an agency such as the Texas Highway Department or the Bureau of Public Roads.

Continued investigation into this subject, however, indicates that such a platform is being developed by a firm of physicists, LaCoste and Romberg, manufacturers of gravity meters in Austin, Texas. They propose to use the platform as a base from which to measure very accurately small differences in the earth's magnetism or gravity. These differences are used to indicate ore deposits of various kinds. As soon as this platform is sufficiently operable it will be tested as a possible road roughness profilometer at no cost to the project. A discussion of these tests will be included in a subsequent report.

GMR Road Profilometer - The only existing profilometer which appears capable of measuring true profile accurately is the device developed by the General Motors Research Laboratory at Warren, Michigan (Ref 5). The device is small, compact, and relatively inexpensive (Fig 2). The road wheel is mounted on a trailing arm underneath the measuring vehicle. The wheel is held in contact with the ground with a 300 lbs. spring force. The truck mass and truck suspension form a mechanical filter between the road and the accelerometer. The relative motion of a location on the vehicle body and the road wheel is measured with a potentiometer. The accelerometer is mounted on the vehicle body above the road following wheel at a point where the potentiometer fastens to the body. Figure 3 shows a sketch of these components. The signal from the accelerometer and the potentiometer are input into an analog computer which is carried in the vehicle. This

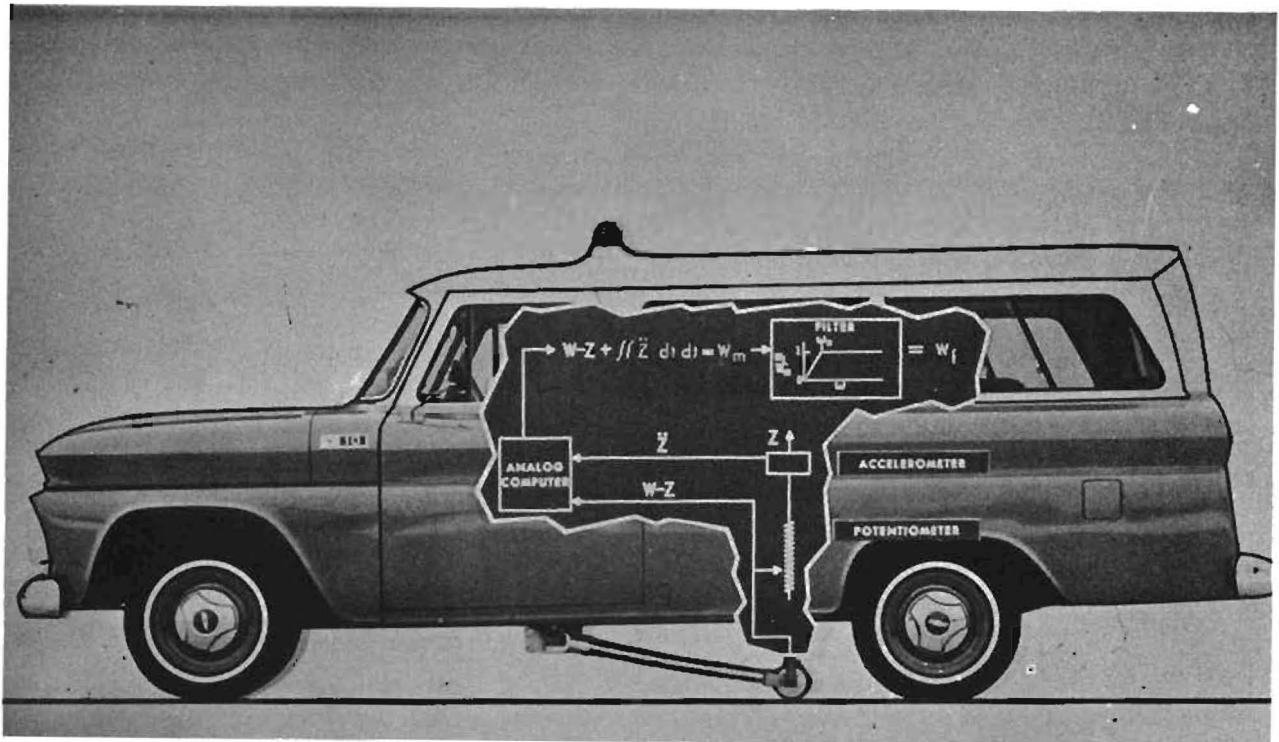


FIGURE 2

General Motors GMR Road Profilometer

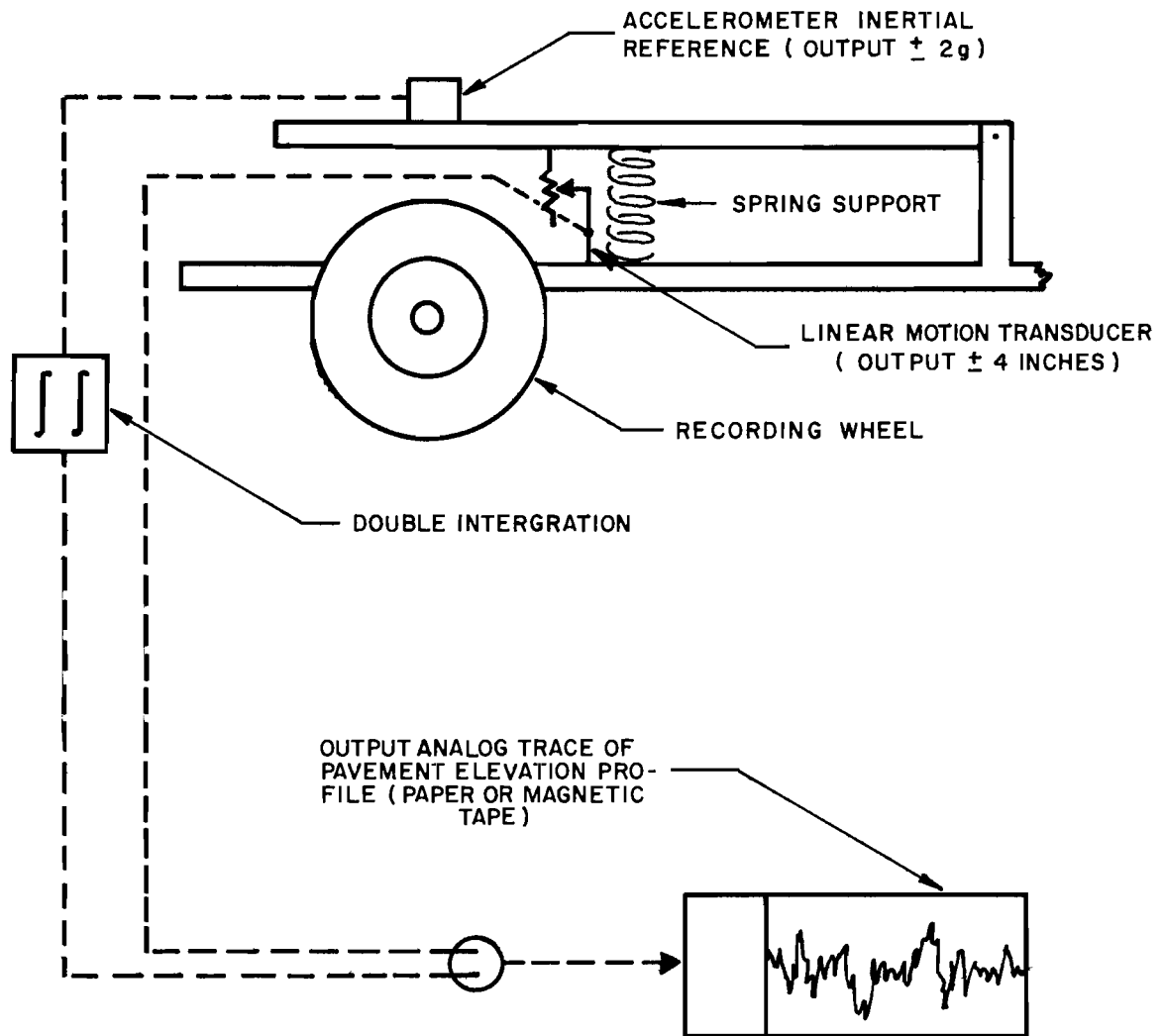


FIGURE 3
Schematic Sketch of GMR Road Profilometer

computer integrates the acceleration signal twice and sums the resulting vertical motions to obtain true profile. The term "true profile" is a slight misnomer since wave lengths longer than about 200 feet are attenuated toward zero in proportion to their amplitude. Thus, it would be better to say that the device gives a good indication of true profile for wave lengths shorter than about 200 feet and produces a signal proportional to true profile for longer wave lengths.

In spite of these apparent shortcomings, the GMR profilometer has shown to be a very effective tool for measuring road roughness. Its main drawback is its output, which is an analog record of the pavement surface. The use of such a device for, say, four hours per day at fifty miles an hour could result in 200 miles of profile per day or the equivalent of 1000 road miles of profile per work week. It is uneconomical and almost humanly impossible to read such quantities of data with hand methods. It seems essential that electronic data processing be coupled with this device to produce a digital output.

With this in mind several efforts have been made to obtain equipment capable of converting the analog output of the GMR device to digital form. Two excellent proposals have been received. One of the proposals is from Lufkin Research Laboratories in Los Angeles, California. Although a relatively new firm in electronic instrumentation, they seem to have the personnel and the background in precision mechanical instruments to do an excellent job. An abstract of their proposal is included in Appendix A. The other proposal was submitted by Austin Electronics of Austin, Texas, a subsidiary of TRACOR, Incorporated. Though a young firm they seem to be competent and enthusiastic. A summary of their proposal is also included in Appendix A. These proposals were developed after several conferences between the Project Director and personnel from

interested firms. While they are not complete in all details, they should provide a good basis for estimating data processing needs and costs. In both cases it appears that the purchase price of such equipment is approximately \$40,000 to \$50,000. A large portion of this cost, however, can be saved by renting part of the equipment on a per mile basis, or by using the equipment for more than one purpose, thus amortizing the cost more rapidly.

In January, 1965, General Motors Corporation announced their intention of marketing their device through a licensed equipment manufacturer to the general public. Unfortunately we have not been able to obtain the use of a GMR device for evaluation. This seems to be primarily due to efforts to license a commercial manufacturer for the equipment. Delays in negotiations have caused considerable delay in gaining the information necessary to complete this project.

The Michigan Highway Department has a copy of the GMR profilometer obtained from General Motors in 1964. Correspondence with them, however, indicates very little progress toward using the tool for measuring true profile. At the present time, they are making no effort to obtain automatic data processing equipment.

The many unknowns involved in this problem make it very difficult to establish accurate cost estimates. For that reason no detailed cost breakdown is being presented at this time. The best available information, however, indicates that the GMR profiler complete with towing vehicle will cost approximately \$20,000. Data processing equipment will cost from \$30,000 to \$50,000, so that the total equipment package will cost approximately \$50,000 to \$70,000.

Statistical Profilometers

In addition to a "true profile" an instrument capable of

measuring roughness and summarizing it in the field is needed for use by the Texas Highway Department. Such information is needed in determining present serviceability index.

Evaluation of this problem has uncovered two types of equipment of potential usefulness for obtaining statistical summaries of pavement profiles, thus providing PSI in the field without the need for digital computers. One of these, the Kentucky Accelerometer, is presently in use in the State of Kentucky and could be purchased and put into operation by the Texas Highway Department within six months. The other device is one being developed by the Lane-Wells Corporation and should be available for commercial rental or purchase by September, 1966.

Kentucky Accelerometer - The Kentucky Department of Highways has furnished us a copy of the plans and specifications for their accelerometer profile equipment. After a cursory examination of this information, the plans were submitted to the Texas Highway Department for their study. The parts and pieces for manufacturing such a device can be purchased for approximately \$2,000. In addition the use of a standard automobile costing approximately \$2,500 is required.

The Kentucky equipment has several distinct advantages but also several disadvantages. Data from the NCHRP study conducted at Purdue (Ref 7) indicate that the Kentucky device can measure PSI just as accurately as the CHLOE profilometer. Furthermore, it operates at speeds of 40-50 miles per hour and therefore qualifies as a high-speed device. Finally, the equipment is already in existence and can be purchased without the delay of commercial developments.

The disadvantages of the equipment cannot, however, be

neglected. As presently used by Kentucky the device involves the measurement of accelerations on a human body riding in a standard automobile. cursory studies published by Kentucky indicate the effect of variations in the physical build of the subject and of the automobile are relatively minor. These factors do affect the profile to a lesser or greater extent, however, the most important effect as might be expected was the quality of the automobile being used. A compact or "stripped, low price car" gives relatively rough profiles when compared with those obtained from higher priced, luxury automobiles.

Lane-Wells Equipment - During recent years the Lane-Wells Corporation, a wholly owned subsidiary of Dresser Industries, has applied its technical knowledge to the improvement of equipment used in highway engineering.

Their best known developments include the nuclear road logger and a device for measuring deflections under dynamic load called a "Dynalect." They have budgeted some \$25,000 for the development of a prototype high-speed summarizing profilometer capable of providing PSI in the field without the requirement for digital computers. The pressure of other work, however, has delayed the development of this prototype and at the present time it appears that it will be late 1966 before the prototype is available for tests. (As this report goes to press the development by Lane Wells Corporation has been suspended until further notice).

DATA PROCESSING AND ANALYSIS

An adequate physical description of pavement roughness is very complicated due to its multi-dimensional nature. Great simplifications are required to describe roughness in terms meaningful to highway engineers. The forces and motion to which the highway user is subjected by this pavement roughness are also very complex. As with many natural phenomena, man's efforts to describe pavement roughness and its effects have lead to empirical correlations; in this case between certain easily defined roughness parameters and the subjective rating of the riding quality of the pavement by the highway user. Such ratings have been termed PSR (present serviceability rating) and the resulting correlation based on certain measurable parameters, PSI (present serviceability index) (Ref 1).

While the PSI concept has been very useful in recent years the problem is by no means solved. Statistical evaluation of pavement ratings (Refs 1, 4 and 7) indicates correlation coefficients for various roughness measurements to be in the range of 60-90 percent. Most of these correlations involve rather elementary use of longitudinal profile information. Better measurements should lead to better correlations.

There is a great deal of reason to believe that continued study of human response to external stimuli and continued study of roadway roughness parameters will lead to better ways of measuring pavement roughness and thus better ways of characterizing the subjective serviceability rating of the highway user.

Most of the factors used in previous correlation work have been rather simple statistics, such as the summation of the

deviations of the deflection profile from some mean value, i.e., the Bureau of Public Roads Roughometer and the Michigan Profilograph. Other statistics include (1) the summation of the area under a continuous analog plot of vertical accelerations and (2) variance of slope measurements taken by a slope profilometer. In every case the development of these statistics has been governed by available economical data handling techniques.

Other more sophisticated data processing techniques have been developed. Coupled with the advent of better data recording equipment these will undoubtedly make the use of the more sophisticated methods meaningful and desirable.

Two such useful data processing techniques are the harmonic analysis and the power spectral density analysis. In general, a harmonic analysis is useful for evaluating periodic or repetitive wave patterns. The power spectral density function on the other hand is most suitable for characterizing random functions. In one case the validity of the analysis depends on the assumption of periodicity; in the other on randomness.

Unfortunately, highway roughness is neither completely random nor especially periodic although periodic wave patterns often develop under repetitive traffic. Examples include 15 foot joint spacing in concrete, and rub-boarding associated with some classes of weaker flexible pavements.

On the other hand, many pavements, particularly flexible pavements and continuously reinforced pavements, are rather more random than periodic.

The harmonic and power spectral analyses are rather complex; however, a practical method of performing them has been developed. Some of the best work available to date has been accomplished by

Hutchinson (Ref 3). Other significant work has been done by Professor Bayard Quinn at Purdue University. A complete discussion of these two methods does not seem to be appropriate at this time since only their use in analysis, evaluation, and correlation of ratings can provide an understanding of their suitability as pavement parameters.

Many other possible methods of analysis present themselves such as an evaluation of body accelerations and the analysis of slope variance, (as done at the AASHO Road Test). In such analyses, it is probable that some measure of frequency and wave length should be considered along with amplitude.

We have previously discussed the two types of profilometers of interest to the highway engineers. The true profilometer capable of giving rather exact reproduction of the pavement surface and the statistical summary profilometer which coordinates data processing equipment in the field and produces a summary statistic which is correlated with riding quality. The development of the true profile equipment will facilitate future research into the problem of correlating the various roughness parameters with riding quality. The high speed statistical profilometer is badly needed to provide highway engineers and researchers with rapid, efficient means of evaluating pavement serviceability in the field.

The type of equipment required for processing and analyzing data is even more diverse than the possible methods of recording the data because the output from each measuring method can be processed in many ways.

In most instances it is desirable to discreetly sample a continuous analog output. Such a technique would be useful in sampling the output of the Kentucky accelerometer equipment and

the GMR profilometer output. The proposals received from Austin Electronics and Lufkin Research Laboratories as previously discussed, describe equipment capable of performing this task and producing the output in a form compatible with high speed digital computational equipment.

Equipment suitable for performing summary calculations and data processing in the field is highly dependent on the transducer and recording equipment. Many such techniques have been employed. These vary from the simple one-way clutch "integrater" used on the Bureau of Public Roads Roughometer, through the solenium electrochemical integrater used by the Kentucky device to the compact special purpose digital computer developed and utilized with the CHLOE profilometer.

In summary, the data processing requirements can be stated as follows:

1. To be useful, true profile information must be easily digitized for machine computations.
2. Summarizing statistical profilometers should be equipped to do routine processing analysis in the field but under certain circumstances digital output which can be processed by digital computers overnight could also be used very successfully.

SUMMARY AND RECOMMENDATIONS

It is not possible nor desirable to make an exhaustive study of existing roughness equipment on the budget of this project. Such a survey would require several studies of the size of the Purdue Study (Ref 7). Furthermore, the instrument which should be evaluated does not yet exist. This instrument is a GMR type profiler with automatic digital data processing equipment; and such equipment is not existent. Lacking this instrument, we have evaluated all available information to recommend a course of action to the sponsors.

Consideration of all data available at the present time indicates that the GMR profiler is the best profilometer which will be available to highway engineers for at least five years. It is high-speed, far more accurate than other equipment available and is compact and efficient in operation. With the addition of proper digital data processing equipment the GMR device can serve not only as a basic tool for evaluating roadway profile parameters and their relationship to riding quality and ultimately to specifications for finished roadway surfaces; but also can serve as a summary profiler for evaluating serviceability (PSI) for pavements as desired by District Engineers and designers throughout the State of Texas. This could include particularly the evaluation of the growing mileage of continuously reinforced pavements as well as

any experimental pavements which are constructed. Such a device would greatly facilitate the continued observation of the sections selected for the Texas road test study.

In summary, it is recommended that:

- (1) This project be extended for one additional year and that funds be budgeted for immediate purchase of a GMR Road Profilometer with compatible digital data processing equipment.
- (2) The GMR equipment be evaluated and put to use as soon as possible by the Research Section of the Texas Highway Department in any way they may desire.
- (3) Project personnel should evaluate the prototype device developed by Lane-Wells Corporation if and when it becomes available and include in the final report of the project the results of said evaluation.
- (4) Every effort should be made to proceed with evaluation of the gyro-stabilized device at no cost to the Texas Highway Department, in order that this information might be available for future studies and further developments.

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APPENDIX A

PROPOSALS FOR DATA
ACQUISITION EQUIPMENT



RESEARCH LABORATORIES, INC.
A SUBSIDIARY OF THE LUFKIN RULE COMPANY

210 WEST 131ST STREET | LOS ANGELES, CALIFORNIA 90061 | AREA CODE 213 • 321-6283

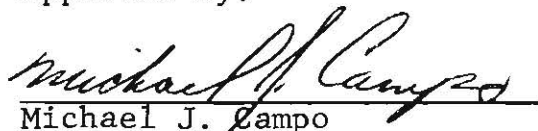
PROPOSAL FOR
A ROAD-PROFILE
DATA ACQUISITION AND PROCESSING SYSTEM

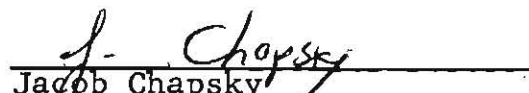
Prepared For
CENTER FOR HIGHWAY RESEARCH
The University of Texas
Austin, Texas

Prepared: 27 April 1965

LRL #WFE:65-145

Approved By:


Michael J. Campo
Manager
Applications Engineering


Jacob Chapsky
Engineering Manager


David R. Stuetzig
President

FOREWARD

This proposal is submitted in response to a letter request - for - proposal dated February 26, 1965, from Mr. W. R. Hudson, Research Engineer, Center for Highway Research, The University of Texas, Austin, Texas.

A Road-Profile Data Acquisition and Processing System comprised of two subsystems is proposed. One subsystem consists of equipment to be installed in a truck, which is to be used in conjunction with a General Motors Corporation Road Profilometer to obtain and record road-profile data in analog form. The other subsystem is an analog-to-digital tape conversion system to be installed in the laboratory, which converts the data on the analog tape to digital form. The digital tape produced by this subsystem contains the data in a format suitable for processing by the General Data Corporation (CDC) Model 1604 Digital Computer presently installed at the Center.

SUMMARY

Lufkin Research Laboratories, Inc. proposes to furnish and install a Road-Profile Data Acquisition and Processing System designed for use with a General Motors Corporation Road Profilometer. The proposed equipment can record and process data from a vehicle containing two road-profile transducer systems.

The proposed system is composed of two major assemblies, one is used for the acquisition of data, and the other for the conversion of the acquired data to a form suitable for processing by a digital computer. The data acquisition components are to be installed in a truck furnished by the customer. They supply reference data that augments the data obtained with the Road Profilometer. A portable, analog magnetic-tape recorder records the Road Profilometer and reference data as analog signals,

and is used in the laboratory to play back the data into the conversion system. The analog-to-digital conversion components are to be installed in an equipment enclosure furnished by Lufkin. This assembly converts the analog data to digital form on a computer-compatible tape.

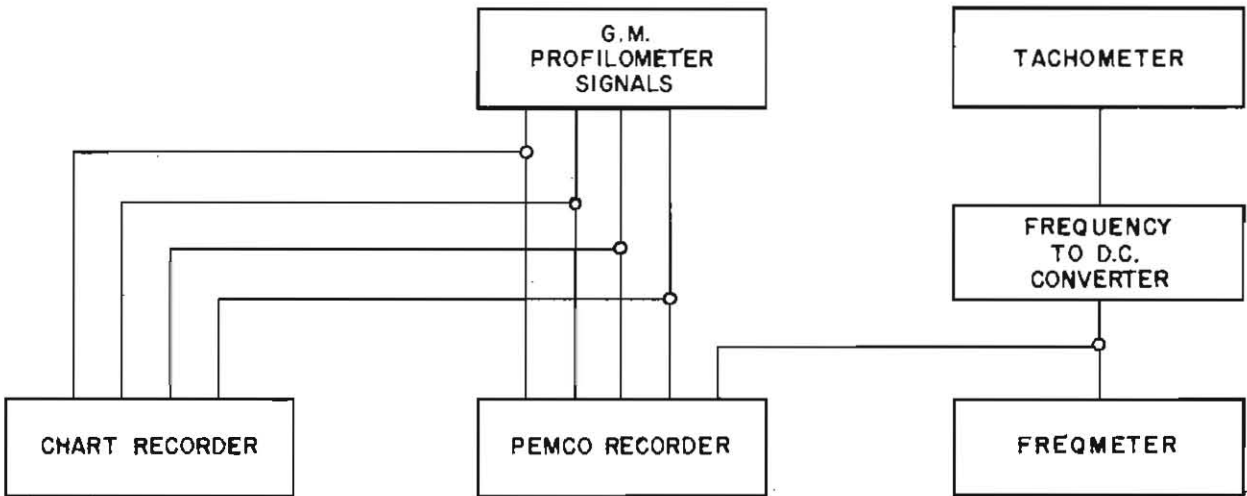
The PEMCO Scientific Data Recorder used to record the data has a 1000-foot reel capacity, giving a recording duration of 26 minutes; consequently, a recording distance of 26 miles when the truck is operated at the maximum acquisition speed of 60 mph. The accuracy of data conversion is 0.5% and the linear resolution is one inch when data is acquired at 60 mph.

A Thermal Writing Recorder is recommended as optional equipment for visually checking the analog data in the field. This chart recorder is not included in the contract price since it is not essential to system operation.

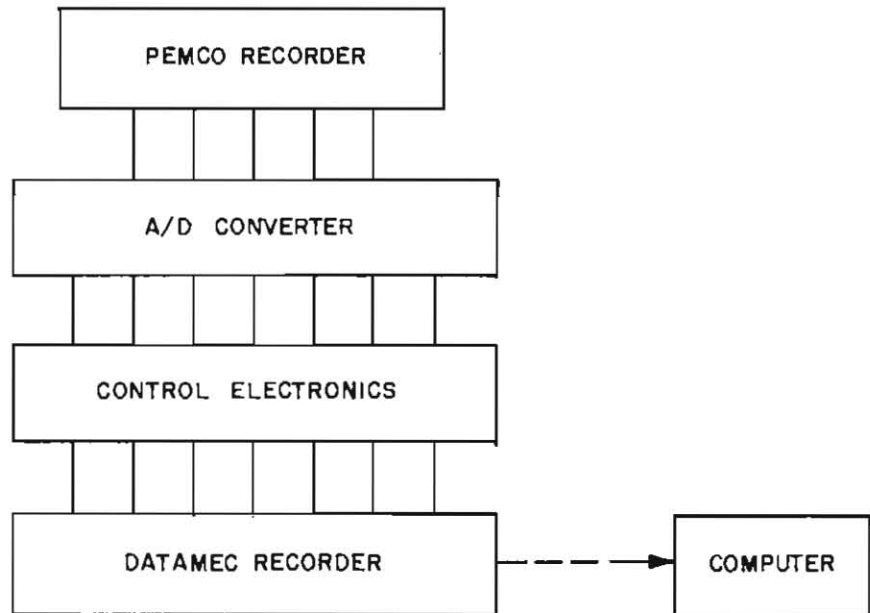
The price of the proposed system is \$41,230. The Thermal Writing Chart Recorder can be furnished for an additional cost of \$4,500. An inverter which will permit the Chart Recorder to operate from the truck's 12 volt battery is available at a price of \$300. The installation of the equipment in the truck will be performed by Lufkin on a time and material basis. Lufkin will guarantee freedom from defects in workmanship and materials for one year, exclusive of major assemblies of other than Lufkin manufacture. Delivery will be made within 120 days after receipt of a purchase order.

LUFKIN RESEARCH CORPORATION
BLOCK DIAGRAM
THD PROPOSAL

FIELD UNIT



LABORATORY EQUIPMENT



6 April 1965

PROPOSED MODIFICATION OF GMR ROAD PROFILOMETER
TO FACILITATE AUTOMATIC DATA REDUCTION

A cost study has been made at the request of Mr. W. R. Hudson to determine the approximate cost of a system to convert the output of the GMR Road Profilometer to a form easily acceptable by a computer. Two different cost estimates are shown below, one for leasing the equipment on an hourly basis and the other constructing a complete data conversion system. The cost shown below is not a firm quote, but is of the approximate value.

A block diagram of the proposed system is attached showing the recording system for the field equipment and the data conversion equipment. The analog data representing the road profile will be recorded on a portable FM magnetic tape recorder. Also the distance markers and voice will be recorded simultaneously on two channels of the recorder. A photocell pickup would have to be added to the GMR Profilometer to give better distance resolution. A tone generator could also be supplied to enable the operator to mark an event on the voice channel by simply pushing a button.

The same recorder could be used in the data conversion equipment for playback purposes. The analog profile data would be digitized by an analog to digital converter and sampled by the distance markers. These markers would probably be spaced every three (3) inches. After the profile data is digitized it will be stored on digital magnetic tape in the form easily handled by available computers. Also a typewriter keyboard will be necessary to add header information on the magnetic tape and control the operation of the whole system. A breakdown of the costs are as follows.

I. Portable Equipment

Parts	\$19,890
Labor	<u>1,500</u>
	\$21,390

II. Data Conversion Equipment


Parts	\$27,330
Labor	<u>4,500</u>
	\$31,830

III. Total Cost

Portable Equipment	\$21,390
Data Conversion Equipment	<u>31,830</u>
	\$53,220

The other alternative of reducing the profile data is to record the data as before and lease time on existing equipment. This equipment can be leased locally at a rate of approximately \$150.00 per hour. The analog data can be played back eight times faster than recorded. This would then cost \$18.75 per hour of data. The cost of the portable equipment above would remain the same and the \$31,830 would not be required. If the \$31,830 was applied to lease the equipment and data was recorded at 25 miles per hour, approximately 42,300 miles of data could be converted.

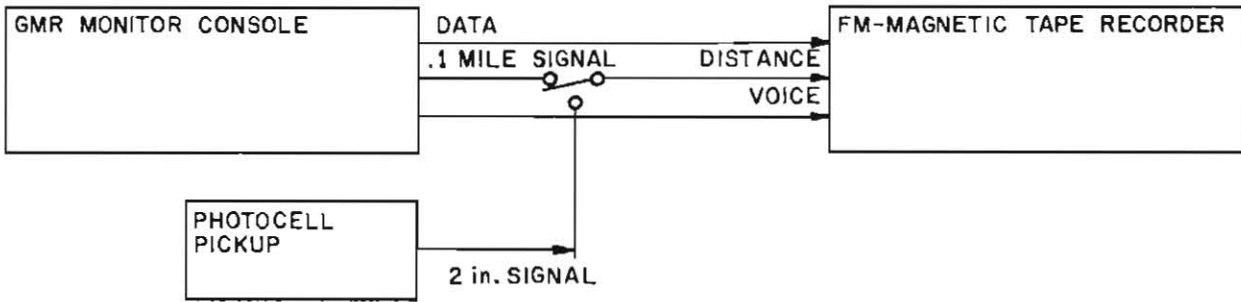
The most economical method of converting the profile data will depend on the number of miles of data recorded and the maximum number of GMR Road Profilometers being serviced.


 G. L. Barr
 Research Engineer

AUSTIN ELECTRONICS CORPORATION
Austin, Texas

PROPOSED MODIFICATION OF GMR ROAD PROFILOMETER
TO FACILITATE AUTOMATIC DATA REDUCTION

I. PORTABLE EQUIPMENT



II. DATA CONVERSION EQUIPMENT

