

WHEEL PATH RUT MEASUREMENT

FINAL REPORT

BY

ZOLTAN G. ZEISKY



OCTOBER 1989

Prepared By

New Jersey Department of Transportation  
Division of Research and Demonstration  
Bureau of Transportation Technology Research

In Cooperation With  
U.S. Department of Transportation  
Federal Highway Administration

## NOTICE

The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

## DISCLAIMER STATEMENT

The contents of this report reflect the view of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official view of policies of the N.J. Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

1. Report No. FHWA/NJ-90-005		2. Government Accession No. N.A.		3. Recipient's Catalog No. N.A.	
4. Title and Subtitle Wheel Path Rut Measurement				5. Report Date October, 1989	
				6. Performing Organization Code N.A.	
7. Author(s) Zeisky, Z. G.				8. Performing Organization Report No. 90-005-7250	
9. Performing Organization Name and Address New Jersey Department of Transportation Division of Research and Demonstration 1035 Parkway Avenue, CN600 Trenton, N.J. 08625				10. Work Unit No. (TRAVIS) N.A.	
				11. Contract or Grant No. NJ HPR Study 7250	
12. Sponsoring Agency Name and Address New Jersey Department of Transportation Division of Research and Demonstration 1035 Parkway Avenue, CN600 Trenton, N.J. 08625				13. Type of Report and Period Covered Final Report June 1983 - Sept. 1985	
				14. Sponsoring Agency Code N.A.	
15. Supplementary Notes Prepared in cooperation with the U.S. Department of Transportation, Federal Highway Administration					
16. Abstract  An investigation was made into pavement management data collection systems and instruments capable of measuring wheel path rut depth. The systems investigated operated on different principles which included light and laser beam reflection, sonic and ultrasonic wave reflection, photographic analysis and video imaging. System operation, capabilities, specifications, and compatibility with other systems were examined with an emphasis on rut depth measurement.  It was found that the benefits of owning a pavement management data collection system capable of measuring and collecting many pavement parameters far outweigh the benefits of owning separate devices which collect data on individual parameters.  It is recommended that the New Jersey Department of Transportation purchase a pavement management data collection system capable of measuring a variety of pavement parameters including rut depth.					
17. Key Words Rut Depth, Wheel Path Rut Depth, Pavement Management, Automated Pavement Measurements			18. Distribution Statement No Restrictions		
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages 19	22. Price N.A.

TABLE OF CONTENTS

	PAGE NO.
Summary and Conclusions.....	1
Recommendations.....	2
Introduction.....	3
Description of Systems.....	5
General.....	5
System Operation.....	5
Capabilities and Specifications.....	12
Costs.....	16
Compatibility.....	17

LIST OF TABLES

Table 1 - Pavement Condition Measuring Systems.....	6
Table 2 - System Capabilities and Specifications.....	14

## SUMMARY AND CONCLUSIONS

To determine an effective means to collect pavement rut depth data an investigation was performed into pavement management data collection systems capable of measuring rut depth. The systems investigated operated on different principles which included light and laser beam reflection, sonic and ultrasonic wave reflection, photographic analysis and video imaging. The systems investigated are summarized in Table 1, page 6. System capabilities and specifications were also examined; Table 2, page 14 contains a summary of this information.

During the early stages of gathering information it became evident that the benefits of owning a pavement management data collection system capable of measuring and collecting many pavement parameters far outweigh the benefits of owning separate devices which collect data on individual parameters. An equipment system which includes the capability of measuring rut depth is therefore preferred.

## RECOMMENDATIONS

Based on the information obtained it is recommended that the New Jersey Department of Transportation purchase a pavement management data collection system capable of measuring a variety of pavement parameters, including rut depth. The purchase of such a system will enable the Department to collect the type and quantity of data required for the development of an efficient and effective pavement management system in the State. This recommendation has already been acted on by the Department.

## INTRODUCTION

Due to the increasing pavement maintenance needs in New Jersey, the need for better pavement management systems is rising. The problem of measuring wheel path rut depth is of particular interest. Manual methods of data collection are crude, basically unsafe, time consuming and provide limited data. A need exists for an accurate and safe automated data acquisition system capable of collecting and processing large amounts of data.

Some existing companies have developed or have under development more sophisticated, and accurate systems aimed at addressing these problems.

In October, 1980, an NJDOT Task Force on Pavement Management was set-up to consider a number of FHWA recommendations regarding New Jersey's pavement maintenance and rehabilitation activities. As a result of this effort a report was issued. One of the more prominent deficiencies identified was the need to upgrade the pavement evaluation methodology presently employed. A lack of data on pavement riding quality and an efficient means of performing rut depth measurements and data collection was noted. This report presents information on existing equipment and systems capable of performing automated rut depth data collection.

The objectives of this project were to survey existing equipment and systems which provide wheel path rut depth measurement capabilities whether separately or incorporated in larger, more sophisticated pavement management data collection systems, and determine the suitability of each piece of equipment

or system for integration into an efficient pavement distress measurement procedure. If a feasible alternative was found, it would be tested and implemented.

## DESCRIPTION OF SYSTEMS

### GENERAL

Of the various systems investigated each operates on a different basic principle, and therefore standardization among the systems has not been established. The systems operate on the following basic principles:

- . light beam or laser beam reflection
- . sonic/ultrasonic wave reflection
- . 35mm photographic analysis with strobe lighting
- . CRT (Video) imaging using electron beam and computer image enhancement (under development)

### SYSTEM OPERATION

Since each system utilizes and works on a different principle, the following discussion will be oriented toward each manufacturer's particular system. See Table 1, page 6 for a summary of the systems.

#### Laser System

The Novaco Laser RST unit consists of a dedicated van, equipped with eleven (11) laser units mounted on the vehicle's front bumper. The two side units are angled outward to increase the cross profile and rut depth measuring width. Pulse transducers are mounted on the front wheel along with a vertical accelerometer to determine road roughness, and distance. A BV-11 skidometer is attached to the rear of the van to measure road fric-

TABLE 1

PAVEMENT CONDITION MEASURING SYSTEMS

MANUFACTURERS	MODEL	RUT DEPTH CAPABILITY	PRINCIPLE OF OPERATION	OTHER CAPABILITIES
Novaco Limited 317 W. Colfax St. Palatine, IL 60067 (312) 991-0580	LASER RST	Yes	Laser With Photo Sensors	Road Roughness Road Friction Distance Road Surface Macrotexture
K.J. Law Engineers, Inc. 23660 Research Dr. Farmington Hills, MI 48024 (800) 521-5245 (313) 478-3150	690 DNC, 8300	No Yes	Light Sensors Ultrasonics	Road Deflection Road Profile Rolling Straight Edge Determines How Much Material is Needed to Smooth Highway Gives VPR/PCA Indexes
PMS, Inc. Pavement Management Systems, Inc. P.O. Box 15804 Lakewood, CO 80215 (303) 232-2207	ARAN PURD	Yes Yes	Ultrasonics	Ride Quality Longitudinal Profile Transverse Cross Section Cross Fall Road Distress Data Skid Resistance Road Cracking General Road Measurements
Pasco Corp. 13-5 Higashiyama 2-Chome Meguro-Ku, Tokyo 153 Japan 03 715-1611	ROADRECON -70 RDP-75 PHP-77	Yes	Photographic	Road Surface Conditions: Cracking Rutting Longitudinal Roughness Pothole Percentage Predicting Future Maint.
Earth Technology Corp. Applied Materials Instrumentation (AMI) 3777 Long Beach Blvd. Long Beach, CA 90807 (213) 595-6611	LABORATORY PROTOTYPE	Yes	Video Imaging and Enhance- ment	System Will Be Used in Conjunction with the PMS, Inc. System to Add Further Capabilities With Greater Accuracy and Versatility - Such as Numerical Results of Scoring, Cracking, Rut Depth, Location and Severity

tion. If wet friction measurements are needed a water tank is installed in the vehicle. Inside, the vehicle is equipped with the amplifier system and power supply for the laser electronics which is fed into an on-board computer with floppy disc drives and a printer. Data also can be manually entered using a control panel and video monitor.

Rut depth is measured according to the straight edge or wire principal - the straight edge method being used for "traditional" rutting characteristics. The wire method is used on pavements with significant crown, flexible pavements or ones having unusual rutting characteristics. Rut depth data and other large amounts of data can be collected and evaluated by this system.

#### Light Beam System

The K. J. Law Company has, at this time, two systems. One is mounted in a van, for pavement management data collection, the Model 690 DNC road profilometer. The other includes the second system which can be mounted in a car or van, the Model 8300 roughness surveyor, with optional rut depth measurement capability.

The road profilometer system uses a non-contact light beam displacement measurement method. The profiles are computed by a digital computer housed in the vehicle, and the profile signals are displayed on a strip chart recorder and also recorded digitally on magnetic tape for later data processing.

The roughness surveyor uses ultrasonic sensors and accelerometers to measure road roughness and has a measuring bar with

five (5) metal film transducers for rut depth measurement mounted on the vehicle's bumper. Rut depth is measured using the straight line technique. The system allows the test vehicle to measure both roughness and rut depth at the same time and record and print independent reports.

### Ultrasonic Systems

The Aran and Purd units are made by PMS, (Pavement Management Systems) Inc. The Aran (Automatic Road Analyzer) system is a van mounted, self contained system whereas the Purd (Portable Universal Roughness Device) requires use of an additional trailer.

The Aran unit contains an on-board computer and sensing devices which allow recording of roadway characteristics at speeds up to 80 km/hr. The information can be surveyed at predetermined sampling intervals ranging from 10 meters to 100 meters with all the information stored in digital form on magnetic tape cassettes.

Transverse cross section is obtained by 13 sonar sensor measuring devices mounted on a bar across the front of the vehicle. A 14th sensor is used for automatic calibration of the other 13, to compensate for variations in air density. (The transverse distance between sensors is 300mm and an accuracy of 2mm is obtained for the relative elevation of each point on the pavement.) Variations in lane widths from 2 meters to 4 meters can be easily surveyed with the addition of extra sensors.

Ride quality, or "traditional" roughness is measured by an accelerometer mounted to the rear axle housing; the roughness result is converted to slope variance, the parameter used for describing roughness.

Longitudinal profile is obtained by further processing the roughness signal on a regular more frequent interval of 10 cm. This allows relative elevations to be generated and a longitudinal profile based on the 10 cm distances. Coupled with this information is grade angle as measured by a gyro, (to accuracies of less than 0.1 percent.)

The cross-fall is sensed by the gyro for the transverse attitude of the vehicle. (With accuracies to 0.1 percent.)

Road distress data is inputted by two (2) keyboards, each having ten (10) distress keys and five (5) special item keys which are available to the operator. Each of the keys relate to a distress type, severity and density. Direct input of the operator's visual estimation of the distress at a particular point on the highway can thus be keyed in. The five (5) special keys are used for such items as bridge location, railroad crossing, culvert crossings, etc.

Skid resistance is inferred from surface texture measurement. Radar technology is used to determine the surface texture in each wheelpath and the skid number is developed from these readings.

A constant speed is not required in any of the measurements. Correlation equations are included in the data processing software and compensate for variations in speed which is constantly monitored.

### Photographic System

PASCO Corporation road survey system consists of a dedicated van (similar to a motor home), which includes the Roadrecon-70 for

cracking survey, the RDP-75 for rutting survey, and the PHP-77 for longitudinal roughness survey. These three systems can be installed individually or in unison in the van, for a complete pavement management data collection system. The method used for roughness measurement is mechanical (tracking wheel), whereas the methods used for cracking and rutting measurements are photographic.

The photographs are made with a 35mm pulse camera, mounted on a cross brace on the front of the vehicle at rooftop height looking at a 90 degree angle toward the roadway surface. Continuous road surface pictures of the pavement are taken to record cracking. The vehicle can be moving between 20-60 km/hr. The continuous strip film is returned to the laboratory where the cracked areas are computed and evaluated using the images projected and enlarged ten (10) times, and a computer system. The section of road photographed is five (5) meters across and is illuminated using ten (10) quartz halogen high intensity 500 watt lamps. A 7.5KVA generator is used for powering the system.

Rutting can be photographed using the pulse camera with a hairline projector unit. This projects a hairline optical bar image onto the roadway surface from 0.8 km/hr and records the image on the film at intervals of 0.1 meters minimum. The hairline projector uses a high intensity strobe flash and is synchronized along with the 35mm camera to the vehicle's speed. The film is returned or brought back to the laboratory, and where the hairline deviates from a straight line across the film, the coordinates and deviations are determined from the photographs by

using a computer. The system for cracking and rut depth is used at nighttime, dusk or near dawn, using artificial lighting mounted on the van. This reduces the chances of causing traffic congestion by the data collection procedure, and provides uniform, repeatable lighting for photographing the pavement. In addition, wetting the pavement is suggested for the cracking survey, to enhance the visibility and definition of the crack image on the pavement for photographing.

#### Video Imaging and Enhancement System

The AMI Inc. (Applied Materials Instrumentation) system was under development at the time of this investigation, however the methods anticipated employ high speed image processing techniques using raster scanned video images recorded on magnetic tape for permanent storage.

Each frame of a standard television image frame is converted to an array of picture elements (pixels) by using a high speed analog to digital converter module. These pixels are processed individually for "gray scale" or color content. The system must be capable of detecting not only the extent of surface cracking, but also the width of the crack in question. High resolution processing requires a pixel frame format of 1024 x 1280. (Typically a television frame is divided into an array of 512 x 512 pixels.)

Cracks are observed by noting the shadow associated with the pavement separation. Since crack shadows are usually much darker than the surrounding pavement, to an image processor the difference in "gray scale" is easily detectable by "threshold" tech-

niques. Pavement surface texture and aggregate color play an important role in the calculation of a suitable value for the threshold, and images of pavement surfaces typically lack the contrast required for reliable processing. In order to do reasonable processing, contrast enhancement, threshold calculation, noise removal and other pre-processing techniques must be used.

A method used to evaluate pavement distress is the shadow moire' technique. Light is passed through a grating, which casts a shadow on the pavement surface. By using proper optical filtering and knowing the system geometry, the distance from the grating to the pavement surface can be determined. By measuring the distance from the grating to the surface of the rutted and unrutted pavement, the depth of the rut can be determined.

This information is fed to an image processor, which records the pixel data on magnetic tape. The data is collected while the vehicle is in motion and the speed of the vehicle and the scanned images are synchronized. Data outputted to the users will be pavement rating algorithms, date of survey, route number, section or station number, condition rating score for each type of distress and total rating score.

#### CAPABILITIES AND SPECIFICATIONS

Some of the available specifications for the various systems are discussed below. See Table 2, page 14 for a summary of this information.

The Novaco Limited, Laser RST, Road Surface Tester is designed to collect the various pavement condition data between the speeds of 10-55 miles per hour (16-88 km/hr.). This data is claimed to be repeatable and consistent between the stated speeds and "virtually" vehicle independent, although limits are not defined.

The data from the laser sensors and camera is processed through an on-board, IBM format computer with two (2) 5 1/4 inch and two (2) 8 inch floppy disk drives - all four drives are double sided, double density. Over two (2) megabytes of storage is provided to handle several hundreds of miles of data collection. This computer is semi-permanently mounted in the van.

The data collected will be reported in a format compatible with the data base made up of one (1) mile sections. Intermediate readouts as frequent as every nine (9) feet are possible. Roughness data is collected on a scale of 1 to 9, and the limits can be adjusted up or down to correlate previously collected data based on the "chloetype" bump meter values of 1 to 5.

The laser sensors (11 units) are mounted on a custom built front bumper that is 8 1/2 feet wide in the operating mode. The two end units are mounted at 45 degree angles so that data can be collected over a lane width of 11 feet. Each laser's accuracy is to 0.2 millimeter or 0.008 inch. Measuring distances or summary intervals are variable. Operating temperatures range from 32 to 105 degrees Fahrenheit.

Calibration is instantaneous and is performed electronically by the operator, and can be performed at whatever intervals deemed necessary; usually two calibration checks per day are sufficient. The time required to calibrate the system is 2 to 3 minutes.

The K. J. Law, Model 8300 is a non-contact road roughness surveyor. Data is collected between speeds of 10 to 55 miles per hour, based on an inertial profile measurement system. The system is claimed to be independent of the vehicle's dynamics, and to

TABLE 2

SYSTEM CAPABILITIES AND SPECIFICATIONS

<u>MANUFACTURER</u>	<u>MODEL</u>	<u>METHOD OF DATA COLLECTION</u>	<u>CONDITIONS DURING DATA COLLECTION</u>	<u>ACCURACY</u>
Novaco Limited	LASER RST	Laser Beam with Photo Sensors, Microprocessor Control with Magnetic Storage, Van Mounted System	All Weather, Day or Night, At Regular Highway Speeds	Rut Depth: <u>+1.5mm</u> Road Roughness: 1-50m 95%, nine grade scales, <u>+0.5</u> scale units. Road Friction: Slip ratio 15%, test wheel load: 1000 N +5% Trailer: 300Kg
K.J. Law Engineers	690 DNC 8300*	Non-Contact Light Beam Displacement Measurement Method, Ultrasonic Sensors, and Accelerometers, Microprocessor Controlled with Magnetic Storage of Data: Van and Car* Mount.	Fair Weather, Day or Night at Regular Highway Speeds	Ruth Depth: <u>+10</u> to 25/1000th of an inch
PMS, Inc. Pavement Management Systems, Inc.	ARAN and PURD	Ultrasonic Sensors, With Videologging Capability, Microprocessor Control and Magnetic Storage of Data. Van Mounted (ARAN), Trailer Unit (PURD)	Fair Weather, Day or Night at Regular Highway Speeds	Rut Depth: <u>+0.1</u> inch
Pasco Corp.	ROADRECON-70 RDP-75 RHP-77	Photographic with 35mm Pulse Camera and Strobe Lighting Microprocessor Analysis of Photos	Good Weather, Dusk Dawn or Nighttime. 40 to 60 Km/Hr Highway Speeds	Rut Depth: <u>+2mm</u>
Earth Technology Corp. Applied Materials Instrumentation (AMI)	Laboratory Prototype	Video Imaging and Enhancement Used in Conjunction with PMS System and Microprocessor Control with Manual Keyboard Input of Cracking Severity	Fair Weather, at Highway Speeds	

give repeatable results. The method used is an ultrasonic system that measures displacement between the vehicle frame and the surface being measured. The resolution of the measurements are on the order of 0.010 inch. Up to 300 miles of roughness data can be recorded on each side of a digital data tape cassette for a total of 600 miles per cassette.

The system should not be used in heavy rain or snow conditions. The probe and accelerometer canister assembly is approximately 8 1/2 inches in diameter, and 24 inches long.

The PMS, Inc. Aran and Purd systems will operate at "normal highway speeds" using the ultrasonic detection method and can measure 30 different road parameters at once. Road roughness is measured at 55 miles per hour using accelerometer compensation on the vehicle. Road cracking information is entered semi-manually by the operator on a keyboard at 20 miles per hour or less. Rut depth measurement accuracies are given as +0.10 inch.

An on-board computer in the van handles all inputs and calculations using a distance measuring unit by Trans Wave, Model K5000, which is commercially available and in case of failure, is easily replaceable. The system also uses a Memodyne cassette tape data storage unit.

The Pasco Corporation, Roadrecon-70, RDP-75 and PHP-77 system can operate at 40 km per hour on rural roads and up to 60 km per hour on highways. It is capable of giving information on road surface conditions such as cracking percentage, rutting within +2mm, longitudinal roughness, pothole percentage, and there is the possibility of predicting future maintenance costs based on

materials needed for repairs. All data is brought back to the laboratory for further analysis and reduction.

### COSTS

In 1985 costs for complete pavement management data collection systems were obtained from selected companies.

The Novaco Laser RST system which was selling for approximately \$400,000 has been taken off the market for sale, and the company has decided to lease the unit to highway departments rather than sell it.

The method for leasing is on a rate per mile basis for two categories:

1. Faster, interstate volume of traffic at around 55 mph which is \$35.00 per lane per mile, and
2. Slower, city traffic rate at \$50.00 per lane per mile.

To perform pavement cracking, width, depth, and macro texture measurements, a speed of approximately 40 mph would be utilized.

The AMI, Inc. system is under development. When completed it is estimated that the system will sell for approximately \$250,000.

The PMS, Inc. system manufacturing the Aran and Purd units will sell the complete Aran package, van with the rut depth bar, gyro unit providing curvature, grade and cross slope, accelerometer for ride quality and 3/4 inch format video logging equipment for approximately \$210,000.

The PASCO system has not returned inquiries about current pricing, therefore it is not included in this section.

## COMPATIBILITY

The systems under review are not compatible with each other or to a fixed standard because, as of yet, there are no defined standards for the various parameters these instruments measure. The various systems employ different methods of measuring pavement data. From the data a value or rating is then derived but none are yet considered standards in the industry. For the case of rut depth measurements, which are expressed in millimeters or inches, standardization is not a problem.

An integral part of each of the systems discussed is the system software. Data acquisition is controlled by the software as is the format of result outputs. The intricacies of each system's software were not examined in detail, but for the purpose of exploring the compatibility of current systems it is sufficient to merely state that each manufacturer's system software design is significantly different. Considering this variation in software coupled with differences in hardware and the lack of standardization of outputs, it is quite evident that current systems are not compatible.

Manufacturers are striving to further develop pavement management data collection systems by incorporating additional features into the systems and making other improvements. Therefore, they are constantly updating, modifying and improving their products. However, there are some companies which have systems that differ widely from established methods of operation and which have the potential to improve on existing methods of pavement management data gathering.