AUTOMATED PAVEMENT RUT DEPTH MEASURING SYSTEM

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State of Alaska
Department of Transportation and Public Facilities
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by

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ABSTRACT

The State of Alaska is in dire need of a safe, high-speed, reliable, accurate, and cost effective means of obtaining pavement wheelpath rutting depths for annual road surface inventory purposes. This report consists of an investigation into what devices and methods are currently available and capable of fulfilling these needs. It is recommended that the state begin developmental work on a vehicle mounted system which employs a non-contact optoelectronic means of acquiring these depths, a microprocessor based on-board system to process the data, and a magnetic tape unit for bulk storage of the information. This information would then be easily transferable to the existing computer system for analysis and placement in the roadway inventory data bank. The cost for such a system is estimated at $185,000.00 with the unit to be available approximately one and one half (1½) years after initiation of the design and developmental work.
I. Introduction - The Concerns of Pavement Wheelpath Rutting

Wheelpath pavement ruts, of which all motorists are familiar, arise from several sources:

1. plastic deformation in the pavement or subgrade material due to repeated differential loading,

2. abrasive effect of tire studs on the pavement surface, and

3. differential longitudinal roadway foundation settlement; for instance, ditch area consolidation in thaw unstable permafrost locations.

Rutting, whatever the cause, presents a major traffic hazard to the roadway user and may be indicative of the structural condition of the pavement surfacing. The presence of water in ruts can lead to reduced tire-pavement contact, ice formation, non-uniform friction, non-uniform rolling resistance, reflection from oncoming headlights, splash and spray and internal road damage. Hydroplaning is generally considered the most serious hazard. Even during dry conditions, the ruts can lead to non-uniform friction, steering difficulties, offset tracking, road damage and interruptions of traffic for repairs.

As a general rule, depths greater than 1/4 inch are considered conducive to hydroplaning, with depths greater than 1/3 inch associated with driver avoidance, and depths greater than 1/2 inch with steering difficulties. Ruts 3/4 inch or more in depth are frequently considered serious enough to warrant corrective action.

According to acknowledged pavement management experts, rutting is also an indicator of pavement distress. Although wheelpath rutting is primarily a roadway safety hazard, its presence can accelerate a pavements demise by enhancing the opportunity for water to penetrate the matrix and weaken the pavement and its subgrade material. Correlations of rut depth with various pavement material properties are currently being investigated by the Research Section of the State DOTPF.
The need for an adequate policy for the allocation of available roadway funds necessitates the development and application of objective criteria for maintenance and reconstruction of the existing roadway network. These criteria deal mainly with road surface characteristics, of which wheelpath rutting is a part. To this end, DOTPF is currently involved in performing a biyearly inventory on the physical attributes associated with all the paved roadways in the state. This inventory is expected to continue for an indefinite period for the purpose of generating a working data bank to be used as basis for the rational planning of these roadway programs as well as developing better roadway designs.

As such, reliable, accurate, cost effective, and safe means of acquiring the information for this program is to the States advantage. At present, the parameter which suffers the greatest need for improvement in this regard involves measurement of the extent of wheelpath rutting. Measurements are now taken with a 5 1/2 foot hollow aluminum bar, which serves as a straightedge, through the center of which a mechanical dial indicator is mounted. (See Figures 1 and 2) Its manner of usage on a two lane road is as follows:

1. Support vehicle stops at the sampling point - technician disembarks with straightedge.

2. Judgment made as to location of deepest portion of rut.

3. Measurement taken by placement of dial indicator foot in rut and laying bar normal to the wheelpath direction and noting indicator deflection.

4. Repeat procedure in each of other 3 wheelpaths.

Although this procedure is very straightforward and simple, there are a number of real disadvantages; namely:

1. The procedure is dangerous. Narrow and winding portions of the
RUT DEPTH MEASUREMENT BEAM
IN CURRENT USE BY ALASKA DOTPF

FIGURES 1 AND 2
State's roadway system offers limited visibility to both the technician kneeling in the roadway and to approaching vehicles. To date there have been no accidents resulting from the surveys, but there have been several unsettling instances. The use of trailing and leading flag persons adds additional expense to the operation and may not prevent mishaps, only alter the location. Other portions of the roadway system are difficult to measure due to high traffic volumes. These locations dictate early morning measurements, when possible, or partial traffic disruption. The general situation tends to instill a degree of wariness into the measurer which, in certain instances, erodes the accuracy of the technique and results in poor data.

2. The procedure is both time consuming and expensive. A set of four wheelpath measurements requires, on the average, four minutes to perform at a cost to the State of nearly $3.25. By this procedure, an average of 5 sample locations per mile over the entire 2000 mile roadway system results in a state-wide rut depth acquisition expenditure of $32,500. The analysis, coding, and entry of this data onto the computer files involves an additional $5,000 per survey.

3. The data acquired in this manner constitutes too small a sample to accurately reflect a roadway's true average rut depth. If several of these measurements were sampled at sites which were uncharacteristic of the roadway as a whole, the overall low number of samples taken can result in a distorted picture of the roadway's rutting character. A higher density of samples and an ability to exclude uncharacteristic pavement sections will cause "outliers" to lose their significance. The following table addresses how the number of samples taken relates statistically to the expected error in the measurement and the associated confidence that can be given to that measurement.

<table>
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<th>Number Samples Per Mile</th>
<th>Confidence in Measurement</th>
<th>Expected Error</th>
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<tr>
<td>5</td>
<td>90%</td>
<td>≤ 0.525 inch</td>
</tr>
<tr>
<td>5</td>
<td>&lt; 50</td>
<td>≤ 0.100</td>
</tr>
<tr>
<td>27</td>
<td>90</td>
<td>≤ 0.100</td>
</tr>
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II. In Search of a Better Method

It is hoped that two points have been established:

1. knowledge of a pavements rutting characteristics is important both from a traffic safety and pavement distress point of view, and

2. the present means of acquiring this knowledge through the manual use of a straighhtedge is barely adequate.

The purpose of this study was to investigate alternative means of acquiring pavement wheelpath rutting information, investigate the pro's and con's of available techniques, establish some guidelines for such a device which would meet the States needs, and provide some basic estimates both in terms of cost and delivery for an operable system. In order to fulfill this mission, it was necessary to establish, in a conceptual sense, what it was that the State wanted. Much of the criteria evolved naturally from what was wrong with the old method. Primarily, the device must be able to substantially enhance the safety, speed, ease, and accuracy of obtaining wheelpath rutting information. For the instrument to indeed address the problems associated with the existing technique, it must be characterized by the following attributes:

1. Safety - The measurements must be taken in a manner which minimizes hazard to both the device, its operator, and the traveling public. The device ideally should be innocuous to normal traffic and normal traffic patterns.

2. Speed - The device must be capable of obtaining and processing measurements from an unprepared surface at a rate sufficient to allow movement within traffic at the prevailing traffic speed and to amply sample this parameter at those speeds. This characteristic dictates some type of electronic measurement technique and microprocessor based data handler. Given that the device can travel rapidly and that minimal operational attention is needed, a complete survey of the State roadway network can be performed quickly and inexpensively.
3. Reliability - The nature of a device outlined thus far must be a great deal more sophisticated than a simple straightedge and so the question of reliability becomes an important consideration. A high priced, maintenance intensive system should be avoided.

From the literature search it was learned that no commercially available automated pavement rut depth measuring device exists on the market today. The necessity for pavement surface monitoring devices has been a fairly recent development, particularly in the U.S.A. Agencies in various 
foreign countries and now in the U.S.A. have had to develop their own instrumentation in regard to their particular attribute of interest, and have done so with varying degrees of success. A lack of consensus on what attributes of a roadway are of interest, and the absence of a major road surface monitoring manufacturer has left a void in the market which is being filled on an individual basis. Agencies have been and are currently designing systems specifically for their own needs, setting their own standards, and absorbing the complete developmental cost.

This discouraging state of affairs prompted efforts to investigate what manner of system the State could devise with today's technology. This "bake our own" approach in the development of such a system has some attractive features:

1. The State would get exactly what it wanted, there would be no need to modify an existing system.

2. The system could be designed in a manner to allow for future expansion into the measurement of other roadway surface attributes.

3. An Alaskan firm could be responsible for a substantial portion of the units design and fabrication. The inevitable need for system maintenance could then be handled locally by personnel familiar with the system.

The disadvantages include:
1. funding the entire developmental cost of such a system,

2. uncertainty in the performance of an unknown system which cannot be evaluated as an entire unit before purchase, and

3. expense for input and output data format modification.

The major concern which all agencies face in developing systems of this nature is the need to employ some reliable and accurate means to measure the distance from the roadway surface to a reference plane or point within the transporting vehicle. Different designs have addressed this problem in a variety of ways, which include mechanical, acoustical sounding, and various optical techniques:

1. Mechanical - This method represents the first major effort to improve upon the straightedge. These devices rely for the most part on transverse sets of contact rollers mounted on individual spring loaded lever arms to determine this distance. The first major obstacle this design confronts deals with insuring continuous roller contact at moderate speeds. Secondly, the dynamic behaviour of the supporting trailer or vehicle requires extensive filtering to isolate the signals of interest. The jungle of mechanical parts and pieces that are necessarily associated with such a system present continual difficulties particularly in regards to maintenance. These and other stumbling blocks have hampered the development of a reliable high speed mechanical system and have prompted late comers into looking at alternative means of obtaining this measurement. But all have not been discouraged, the Swedish Road Surface Testor has been developed along this principle (see Photograph 1 and Appendix B) and a prototype of the design is now undergoing field evaluation. Correspondence with the Swedish Road Institute, which is developing the unit, reveals an unwillingness, however, to make a commitment as to availability and price. From this it might be surmised that the units de-bugging stage may be requiring more time than was originally planned.
SAAB ROAD SURFACE TESTER PROTOTYPE
AS BEING DEVELOPED BY THE SWEDISH ROAD ADMINISTRATION

PHOTOGRAPH # 1
2. Acoustical – A number of techniques are under development which allow displacement measurements to be achieved without physical contact. Several of which are acoustical in nature. The fundamental advantage this technique offers over the mechanical concept is the absence of the road surface contact requirement.

An acoustical wavefront is generated at the vehicle and directed downward towards the road surface and the returning echo monitored. Variation in the distance between the pavement and the sensor results in either a variance in the sound wave travel time or a phase shift in the returning wave form. This information coupled with the waves velocity of propagation permits the distance to be computed. However, there is a fundamental problem with this method. Air, the conducting media through which the sonic energy must be conveyed, transmits the wave at a velocity which is dependent on several factors, temperature and pressure being the most predomi-
nate. In the event that the velocity used in the computation of the travel distance were to undergo short term variations, errors would be introduced into the distance determination. Other factors which would affect system accuracy are variations in lateral air speeds and ambient noise sources.

These and other problems do appear surmountable given sufficient research and development effort, the extent of which may be large. The Federal Highway Administration is currently sponsoring a considerable amount of research in this area. According to their reports, although the method shows great promise for use in pavement surface profiling, problems still exist.

3. Optical – The other major area in which a generous amount of effort is being expended is in the use of optics to monitor this displace-
ment. Agencies in several countries are engaged in this endeavor.

The Japanese Road Research Organization has adopted an optical method which employs a collimated beam of light and a thin wire to cast a shadow across the width of a lane. The depth of the shadow
in the wheel tracks, photographically obtained, gives a measure of the rut depth. The main disadvantage of this method concerns the necessity for a substantial amount of visual data interpretation.

The most promising technique available today involves an optoelectronic technique which has been developed in Sweden, U.S.A. and Britain. A light source consisting of an infrared Light Emitting Diode (LED) or a laser diode is projected onto the roadway surface and its point of incidence monitored by means of a linear array of photodiodes using an optical imaging system. The location of the illuminated photodiode within the array indicates the position of the surface relative to the sensor. Variation in the distance to the roadway surface will result in a change in the location of the focused spot's image, as portrayed in Figure 3.

The Federal Highway Administration (FHWA) has sponsored the developmental work on such a unit in the U.S.A. through Southwest Research Institute (SwRI) of San Antonio, Texas. A prototype system, designed to measure simultaneous roughness, rutting, and topography attributes, has been fabricated and is now being tested in the field. Problems which stem from the unit's complexity still exist and are now in the process of being remedied. How much of this trouble originates with the displacement transducers remains unknown.

The British Transport and Road Research Laboratory developed a non-contact optoelectronic sensor, very similar to the U.S. unit, for use in their high-speed roadway longitudinal profilometer. Recent correspondance indicated satisfactory field performance of the unit and current interest in applying the same unit to the measurements of rut depths.

Selective Electronic Inc., a Swedish based multi-national electronics marketing firm, has made commercially available a unit designed along this same principle (See Appendix C). According to the company's literature, the unit has been used successfully by the National Swedish Road and Traffic Research Institute to undertake
BASIC NON-CONTACT OPTOELECTRONIC DISPLACEMENT TRANSDUCER DESIGN

FIGURE 3
fast and accurate road surface macrotexture measurements. Provisions for lens protection from water spray and traffic induced dust have been developed. Design refinements allow for wide variations in ambient light, surface reflectivity, texture, and color. However, surfaces which offer low scattering levels and coarse textures are inherently troublesome to this technique. Before making a firm commitment to pursue an avenue which employs this technique, particularly this device, a preliminary hardware evaluation should be made on black, wet, and coarse roadway surfaces. An inquiry into why the Swedish Road and Traffic Research Institute did not utilize this unit in conjunction with the Road Surface Tester has remained unanswered.

A useful rut depth measuring system entails a good deal more than just displacement sensors. Components are needed for the processing of rut depth information, storage of processed information, calibration of the sensors, and entry of dates, routes, codes, etc. All of these components offer no conceptual difficulties. This portion of the design should be obtainable through any competent computer systems firm which possesses expertise in microprocessor software development and the ability to interface digital equipment. Due to the importance descriptive digital data has in rendering information such as rut depths useful, much of the development of this portion of the system would be necessary— independent of system selection.

III. Options

At this time what options are available to the State of Alaska in regards to a safe, high speed, accurate, and reliable pavement rut depth monitoring instrument?

1. The Saab Road Surface Tester as being developed by the Swedish Road Administration and Swedish Road and Traffic Research Institute will be available sometime in the near future (See Appendix B). In addition to wheelpath rut depth measurement and recording capacity, the unit is slated to be capable of monitoring braking force
conditions on wet and dry surfaces, tire rolling resistance, roadway evenness, wheelpath rut volumes, wheelpath rut pool depth, and curve radius. Provisions to allow manual entry of information on pavement cracks, wear, patching, and shoulder settlements for storage on magnetic tape are planned for the unit.

Correspondence with the Swedish Road Administration and the Swedish Road and Traffic Research Institute has revealed that one or two prototypes have been fabricated and are in the process of undergoing field evaluation tests. Several queries as to availability and cost have all remained unanswered. Officials with the FHWA estimate an eventual cost of $250,000 and the commercial availability to be some time soon. These same officials express doubts as to the high-speed reliability of the unit, mainly due to the mechanical nature of the displacement gauges. Data entry and format modifications will be required for standardization to the convention now used by the State in its inventory data bank. The extent of this possible revision is unclear due to the nebulousness of what will be available. Another concern, which should not be taken lightly, is the remoteness of the manufacturer from Alaska. Language, currency and possible transportation handicaps could severely inhibit maintenance of the unit.

2. At this time the only other viable option open to the State of Alaska is the in-house development of a system along the lines outlined by the FHWA. The technology now exists for the development of a reliable system which meets most of the specifications as outlined in Appendix A. A local Alaskan firm or possibly SwRI could be contracted to design and assemble the unit from specified components. A complete system, field evaluated and ready for inventory use, is estimated to cost approximately $185,000. Delivery could be expected a year and a half after initiation of the program with the evaluation period to include several months of warm weather testing.
IV. Recommendations

The heavy investments undertaken by the FHWA and the British Transport and Road Research Laboratory in the development of non-contact optoelectronic displacement transducer provides the State with an excellent opportunity to apply this technique to its benefit. Commercially available units, similar to the ones developed by these agencies, appear capable of fulfilling the States need for a non-contact displacement transducer. It is recommended that the State commence developmental work on a van mounted system, as specified in Appendix A, which employs this method of monitoring rut depths. Figure 4 illustrates the recommended system development outline and timetable.

Phase II, budgeted at $35,000.00, should consist of component evaluation and system design. A demonstration of the FHWA's road surface topography inventory system should be requested and a visit to its developer, SwRI, would be beneficial. An evaluation program should be undertaken to examine, under roadway field conditions, the performance of available optoelectronic displacement transducers. After a satisfactory evaluation of both the systems concept and a displacement transducer, the State can be reasonably confident of eventual success in its development of a reliable system. Under this time frame, fabrication and field evaluation of the design would then be contingent on the receipt of funds requested for FY82. The system should be operational for the summer of 1982.
AUTOMATED WHEELPATH RUT DEPTH MEASURING SYSTEM

ACQUISITION outline

PHASE I

INVESTIGATION OF ALTERNATE RUT DEPTH MEASUREMENT METHODS

SEPT. 1980

PHASE II

PHYSICAL EVALUATION OF EXISTING SYSTEMS OF INTEREST AND APPLICABLE NON-CONTACT DISTANCE MEASURING TRANDUCERS

DEC. 1980

EVALUATION SUCCESSFUL

NO

WAIT
1) TECHNOLOGICAL ADVANCES
2) AVAILABILITY OF SAAB ROAD SURFACE TESTER

YES

BEGIN DEVELOPMENT

JAN. 1981

PHASE III

FABRICATION

APRIL 1982

DEBUGGING & FIELD EVALUATION

JUNE 1982

OPERATIONAL UNIT

JULY 1982

FIGURE 4

15
ACKNOWLEDGEMENTS

The Alaska Department of Transportation and Public Facilities gratefully acknowledges Dr. R. Hegmon, Federal Highway Administration, and Mr. J. Derwin King, Southwest Research Institute, for their guidance and encouragement in this endeavor.
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Appendix A

SPECIFICATIONS

AUTOMATED WHEELPATH RUT DEPTH MEASURING SYSTEM (ARMS)

I. GENERAL

The Alaska Department of Transportation and Public Facilities (DOTPF), Research Section, is in the process of developing an Automated wheelpath Rut depth Measuring System (ARMS) for use on paved roadways within the state. This outline constitutes the specifications for such a system. In general, the system is to be mounted on a van in such a manner as to allow rapid and accurate measurements of rut depths while the van is traveling on a roadway in the usual manner at normal traffic speeds. The system must be capable of acquiring this information without the prior preparation of the roadway surface and able to withstand a fair amount of abuse from its environment and operators.

The system is to be designed and fabricated to meet these and the following conditions. Acceptance shall be contingent on the results obtained during a period of rigorous field testing of the completed system. This evaluation will be conducted by the contractor under the supervision of a person representing Alaska Department of Transportation and Public Facilities. The contractor will be responsible for the delivery of the system to Fairbanks, Alaska.

II. RUT DEPTH AND PAVEMENT SURFACE DEFINITIONS

Rut depth is defined as the distance to the bottom of a rut measured from a straight line established by the pavement on either side of the wheelpath. The sketch on the following page may be useful in visualizing how five transducers could be configured to acquire these distances in two rut lanes. Rut depth for Lane A would be calculated by subtracting the distance measured by Transducer 2 from the average distances measured by Transducers 1 and 3; the rut depth for Lane B
would be calculated in a like manner.

With this definition and the placement of the measuring transducers as close to the pavement surface as permissible, adverse effects due to the pitching and rolling of the vehicle body should be minimized.

Definition of the "pavement surface" will be strongly influenced by the technique used for the measurement, the extent of the area sampled and the surface characteristics of that sampled area. Hopefully, the distance measurement technique can be adapted to some rational definition of "pavement surface" instead of the inverse occurring. This will allow for a more direct comparison of values obtained either from a variety of pavements having different surface characteristics, or separate rut depth measurement techniques.

Ideally, for this purpose, the pavement surface would be the lateral elevation found by averaging the surface roughness in an area approximately two to three inches in diameter.

III. VEHICLE

The contractor shall supply, as part of ARMS, a standard 3/4 ton van of American manufacture onto the front of which the wheelpath rut depth measuring system is to be mounted. The display and control panel shall be positioned within the van in such a manner as to allow easy viewing and access by either the driver or a front seat passenger. All components of the system shall be securely attached to the van to protect the components from vibrations and shocks normally associated with a vehicle in transit. Further specifications associated with the van:

A. The color of the van shall be safety yellow.

B. Safety signs and signals shall be securely mounted or attached to the exterior in such a manner as to allow a high degree of visibility. These shall include:
1. A rearward visibly directional traffic arrow board mounted to the roof of the van of dimension no less than 1 x 4 foot. The control of this board shall be interior to the van within easy reach of the driver.

2. Flashers or strobes that are visible from the front and rear of the van. The control of these flashers shall be interior to the van within easy reach of the driver.

3. Front and rear mounted "WIDE LOAD" signs for use at times when the displacement transducer support bar measures greater than 8 feet in width.

4. Rear mounted "SURVEY VEHICLE - FREQUENT STOPS" sign.

C. The van shall be equipped with a heavy duty towing package to include anti-sway bars. This is to allow towing of trailers which house additional road survey instrumentation.

D. The van shall be equipped with a Cruise Control unit designed to automatically regulate the van's speed over the range 35 to 60 mph. To permit constant speeds in mountainous and rolling terrain where steep uphill grades may be expected, an engine capable of generating a generous amount of horsepower is needed. This requirement can be met by a 350 or greater cubic inch displacement engine.

E. Other requirements are dual batteries, high output alternator, high output heater, auxiliary fuel tank, pair of high quality low profile rear view mirrors, intermittent windshield wipers, rear and side windows and an AM/FM radio.
IV. SYSTEM INPUTS

A. Rut depth measurements

Five non-contacting distance measuring transducers shall be configured in such a manner as to allow for the determination of two rut depths - one for each wheelpath. These devices shall be securely mounted on the outside frame of the van and must be comparatively easy to adjust laterally to allow for variations in rut lane separations. They shall be mounted and protected in such a way as to guard the units from hazards caused by flying gravel and other debris. The two outer sensors, along with any necessary mechanical supports, must be designed in such a manner as to allow for the easy conversion of the structure to a width of less than six feet for transport to and from areas to be sampled. The maximum allowable width permitted inclusive of the outer sensors is ten feet.

Characteristics which these transducers and the data acquisition system must exhibit and satisfy are:

1. Dynamic measuring range of ± 2.5 inches from a nominal sensor height of less than 15 inches

2. Resolution of 0.01 inches

3. System accuracy (short term) of ± .03 inches

4. All calculated ruts greater than 2.5 inches and less than 0.0 inches (which would represent a negative rut) to be excluded from the averaging computations.

5. Simultaneous rut depth measurements at the selected sampling location; however, if the five pavement distance measurements must be sampled serially, this sampling period must not exceed 1 millisecond. The distance interval between a set of samples
is to be operator specified.

6. Capable of operating under a wide range of asphaltic pavement surface textures, surface colorings and ambient light conditions under the stipulations outlined above.

7. Transducers must remain operational in an environment likely to consist of vibrations, water spray, static electrical charges, grit, temperatures ranging from 0°F to 100°F, air speeds (relative to instrument) ranging from 0 to 100 mph, relative humidities ranging from 10 to 100% and air pressures ranging from 600 to 760 mm of Hg.

The displacement transducers shall be optoelectronic in nature unless it can be shown that an alternate method of acquiring this information to these specifications, can result in a savings to the State of Alaska.

B. Odometer Encoder

The distance the van travels must be monitored to allow for uniform sampling as a function of distance. This shall be accomplished with a bi-directional distance measuring unit (Model K-145 with BCD-output option) manufactured by Nu-Metrics, P.O. Box 800, Connellsville, Pennsylvania 15425. The unit shall be modified in such a way as to make it consistent with the needs of the system. Three parallel output ports shall be available from this unit for the purpose of providing distance traveled and milepost information to ARMS and other pavement survey instrumentation.

C. Manually Entered Data

The ability to introduce the following information into the system by means of a key board must exist. This information, descriptive in nature, will be used for bookkeeping and sample control purposes.
1. CODE (NNNNNN) - to consist of a six digit integer

2. DATE (YYMMDD) - to consist of a six digit integer

3. DIRECTION OF TRAVEL (NNN) - to consist of a three digit integer

4. SAMPLING RATE (NNNN samples/mile) - to consist of a four digit integer

5. AVERAGING INTERVAL (N.N miles) - to consist of a real number having a resolution of 0.1 miles. This informs the system over what traveled distance interval the average and the standard deviation for each rut depth is to be computed.

These computations will be initiated when the mileage accumulator reaches the first mile interval specified and then at each interval thereafter. For example, if the STARTING MILEPOST is 293.27 miles, the MILEAGE ACCUMULATOR MODE is + and the AVERAGING INTERVAL is 0.5 miles, then computations will be performed at miles 293.50, 294.00, 294.50, etc. Initiation of paper and magnetic tape outputs will be in response to completion of these computations.

D. Sample Actuation

A hand held thumb activated ON/OFF switch will allow the operator to deactivate the sampling mechanism in areas where the existing pavement surface is no longer representative of the original pavement surface. This will allow system deactivation in areas of patching, potholes, railroad tracks, bridges, etc. The averaging components will continue to output as specified by the averaging interval, but only on that data obtained over that distance where good data is expected (sampling switch ON). There shall be a display mounted pilot light which indicates the state of the switch.
A measure of what percentage of the interval was sampled over a given distance will be displayed in the output as "% OF INTERVAL SAMPLED". For instance, in the case of a distance interval where there were no patches, potholes, etc., and the sampling switch was ON 100% of the interval, then all data collected over this interval would be used in the averaging and standard deviation calculations and the output would indicate that the interval was sampled 100%. If, however, in the case of a distance interval of 1.0 mile where 0.3 mile consisted of patches (the sampling switch was turned OFF for a distance of 0.3 mile), then only the data collected during the other 0.7 mile would be used in the calculations and the output would indicate that the distance interval was sampled 70%. This sampling switch will not have any effect on the mileage being accumulated and the output - that is, it will be possible to output data at the end of a specified distance interval during which the sampling switch was always turned OFF, resulting in 0% sampled. In this unlikely situation, there would be no input data and the output should reflect the situation.

E. Start/Reset

This switch will be used to initiate output and clear the data registers to allow for the beginning of a new sampling interval. Control of the "HOLD" feature on the Nu-Metric DMI shall be linked to this switch.

F. Calibration

The system must be designed in such a manner to permit frequent displacement transducer calibration checks. In the event that calibration adjustments are needed, a simple procedure for providing the necessary adjustments must exist. The hardware and electronics necessary to accomplish this task must accompany the system and be configured as to allow for easy transport and access within the van.
V. SYSTEM OUTPUTS

A. Continuous Display

Before and during the course of sampling, the following information shall be visible on liquid crystal displays for the purpose of reassuring the operator that the system is functioning correctly and that the descriptive reference data were indeed entered correctly.

1. CODE (NNNNNN) - initially entered code for the purpose of test section designation

2. DATE (YYMMDD) - initially entered date

3. DIRECTION OF TRAVEL (NNN) - initially entered direction of travel code

4. MILEAGE (NNNN.NN miles) - mileage accumulator which will equal the initial STARTING MILEPOST +/- distance traveled from the position where the START/RESET button was activated. This number will be the duplicate of the position as displayed by the Nu-Metric DMI.

5. SAMPLING RATE (NNNN samples/mile) - initially entered sampling rate, function of distance

6. AVERAGING INTERVAL (N.N miles) - initially entered averaging interval, function of distance

7. RUT DEPTH LANE A (N.NN inches) - The rut depth as measured in Lane A. The data needed to provide this information is the same data which is used to calculate the average rut depth as printed at the end of a sample interval. However, the rut depth displayed here is to be regularly updated as a function of time. This will allow continual feedback to the operator on
the systems performance during normal operation and for calibration purposes.

8. RUT DEPTH LANE B (N.NN inches) - the rut depth as measured in Lane B.

B. Printed Paper Tape

Initiation by either the completion of the averaging interval or a START/RESET will cause final average and standard deviation calculations to be performed on the rut depth data acquired from both lanes and induce output by means of both printed paper and magnetic tape. Data to appear on paper tape shall include:

1. CODE - (NNNNNN)

2. DATE - (YYMMDD)

3. DIRECTION OF TRAVEL - (NNN)

4. MILEPOST - (NNNN.NN miles)

This milepost designation shall equal the lower mileage which brackets the sampling interval, regardless of direction of travel. For example, if the STARTING MILEPOST is 73.64 miles, the MILEAGE ACCUMULATOR MODE is + and the averaging interval is 0.5 miles; then the first output will be initiated at mile 74.00 with the MILEPOST listed as 73.64. The next output which represents values over the interval 74.00 to 74.50 will list 74.00 as the MILEPOST.

5. SAMPLING RATE (NNNN samples/mile)

6. AVERAGING INTERVAL - (N.N miles)

7. AVERAGE RUT DEPTH LANE A - (N.NN inches)
8. STANDARD DEVIATION RUT DEPTH LANE A - (N.NN inches)

9. AVERAGE RUT DEPTH LANE B - (N.NN inches)

10. STANDARD DEVIATION RUT DEPTH LANE B - (N.NN inches)

11. % OF INTERVAL SAMPLED - (NNN)

C. Cartridge Magnetic Tape Data Storage

The same information, in the same order, shall also be written on magnetic tape as it appears on the printed paper tape. Initiation for the information transfer will coincide with the request for paper tape output. The cartridge unit shall be a read/write unit capable of being powered by 120V AC for use in reading the information from the tape at a later date. To allow for the use of a time-sharing computer port via a CRT terminal, to access the data in a rapid manner, the following specifications for tape format and transferral characteristics are required:

1. Transmission - half/full duplex (processor and tape unit switch selectable), asynchronous, serial-by-bit-by-character

2. Code - ASCII, seven bit character plus one bit parity (this parity bit must be generated by the ARMS processor and be switch selectable odd or even)


4. External Data Transfer Rates - 110, 300, 1200 baud, switch selectable

5. Storage capacity of at least 200,000 characters on standard 300 foot DC300A data cartridges

6. The recording system shall be accompanied by 10 blank 300
foot DC300A Verbatim data cartridges

7. The eleven numbers (as listed by the printed paper tape) representing a complete sample interval shall be written on the magnetic tape according to the following format:

<table>
<thead>
<tr>
<th>NNNNNN</th>
<th>YYMDD</th>
<th>NNN</th>
<th>NNNN.NN</th>
<th>NNNN</th>
<th>N.N</th>
<th>N.NN</th>
<th>N.NN</th>
<th>N.NN</th>
<th>N.NN</th>
<th>N.NN</th>
<th>N.NN</th>
<th>% OF INTERVAL SAMPLED</th>
</tr>
</thead>
<tbody>
<tr>
<td>CODE</td>
<td>DATE</td>
<td>DIRECTION OF TRAVEL</td>
<td>MILEPOST</td>
<td>SAMPLING RANGE</td>
<td>AVERAGING INTERVAL</td>
<td>AVERAGE RUT</td>
<td>DEPTH LANE A</td>
<td>AVERAGE RUT DEPTH LANE A</td>
<td>DEPTH LANE B</td>
<td>STAND RUT DEPTH LANE B</td>
<td>DEPTH LANE B</td>
<td>STAND RUT DEPTH</td>
</tr>
</tbody>
</table>

Each number will be separated by one space. The end of this one line of data will be terminated by a [CR] carriage return.

We request a Tektronix Model 4923 Digital Tape Recorder with the RS-232-C interface option for this storage unit.

VI. SYSTEM INTELLIGENCE

At some future date it may be desirable to upgrade the system to allow for roadway cross slope monitoring or longitudinal profiling. For this reason, the processor should be versatile enough to allow for the addition of certain features without major expense or down time.

VII. DOCUMENTATION

The finished system shall be accompanied by a complete set of electrical and mechanical schematics with parts list.
Appendix B

Saab Road Surface Tester Brochure

A brief outline of the only commercial unit to be available in the foreseeable future. The system is now undergoing field evaluation tests in Sweden.
Background

An extensive knowledge of the operative state of the road network is required for the management of maintenance and rehabilitation work, especially when considering the perpetually waning road budget.

Of primary economic importance today in consideration of the future are:

- an improved knowledge and basis for road maintenance
- an objective central allocation of resources
- the development of road standards
- the role of pavement standards in accident analysis
- feedback to highway engineers of pavement wear data

Objective input, to a satisfactory extent, can be obtained only by the use of adequate instrumentation.

Present devices

Existing instruments usually have the limitation of measuring only one variable, and therefore a set of apparatus and measuring teams are required for acquisition of sufficient data in maintenance management. The measuring speed is often low, causing a high operator hazard in heavy traffic. Useful data require extensive and time-consuming data processing.

Need for a new device

The need is great for a reliable integrated measuring vehicle, which can run at the speed of the regular traffic flow, in order to increase security and reduce measuring cost. Simultaneous measurement of several variables and instantaneous data processing are both a must in solving this problem.

The purpose of development of The Saab Road Surface Tester

The purpose was the integration of several well-known measuring principles into one integrated measuring vehicle and application of modern digital computer technology. The purpose has also been to obtain an instrument which is:

- easy to operate
- oneman operated
- easy to maintain
- giving an output which is streamlined for decision

Experience obtained in the development and use of the Saab Friction Tester — a device for measurement of airport runway friction — was an essential ingredient in the development of the Saab Road Surface Tester.
Brief Technical Description

The Saab Road Surface Tester is primarily intended for three modes:

- survey mode 1
- contracting mode 2
- follow-up mode 3

The main parts of the system:

- measuring gauges for the different variables
- signal processing unit
- computer for:
  - control of measuring processes
  - computation
  - result output
- recorder for display of results in print and curve
- control panel for input of reference data, mode selection etc.
- remote control panel for input of ocular observations and control commands
- power supply
- vehicle speed control
- rut depth gauges
- test wheel
- watertank

The main outline of the measuring system:

![Diagram](image)

Fig. 1

![Diagram](image)

Fig. 2
All control information is fed through the CONTROL PANEL, Figure 3, located between the front seats of the Saab 900. Output is displayed on a printer in the control panel. Data recording for future processing is done by the tape recorder shown as a black box in Figure 1.

All electronic equipment, including the computer, are located in the trunk of the vehicle.

Power is supplied from the regular vehicle battery system (12 volts).

The vehicle is equipped with a speed controller for maintaining a constant selected vehicle speed.

![Fig. 3](image)

**Measuring BFC**

For friction measurement, a measuring wheel is installed beside and behind the right rear wheel, size 4.00-8'', hydraulically loaded (1000 N) and retractable. During measurement the wheel has a brake slip of 15%. The braking torque acts by a chain transmission upon the right rear wheel as a driving torque. The test wheel is normally free-wheeling and will, during measurement, be engaged to the rear wheel by a magnetic clutch, thus allowing very short measuring cycles (down to 2 sec).

The test wheel torque and longitudinal force are measured. The measuring distance is controlled by a magnetic pulse counter on the rotation part of the rear axle.

The self watering system includes:

- a built-in levelling system
- a 500 l (130 US gallons) water tank replacing the rear seat of the vehicle
- a water pump giving a constant waterflow per travelled distance independant of the speed. The pump is engaged by a magnetic clutch
- a retractable nozzle giving a flow corresponding to a water film thickness of 0.5 mm (0.02'') in front of the test wheel, within the speed range 30-120 km/h (20-75 mph)

The system allows continuous measurement as well as measurement at pre-set intervals.

**Measuring rolling resistance**

Rolling resistance is measured by the test wheel when in free rolling mode.

**Measuring evenness**

Evenness is calculated from signals generated by an accelerometer on the test wheel. The method has been successfully correlated with panel rankings, and results from measurements with the CHLOE-profilometer.
Cross Profile

Rut depth

Over a width of 2.5 meters every 10th meter (26 measuring points) the individual distance from the car to the road surface is measured by spring loaded small wheels. The wheels can be retracted and the parts extending outside the car (0.5 m on each side) can be folded. The vertical movement of each small wheel is measured (RUT DEPTH GAUGE in Fig 1). The measured values are independent of the lateral motion of the vehicle.

The rut depth is calculated by the computer according to the rut depth definition shown in the figure below:

![Fig. 4](image)

Calculation of estimated rut volume

The estimated rut volume is calculated on the basis of the nominal tilt of the vehicle and the instantaneous output from the rut depth gauge according to the figure below:

![Fig. 5](image)

Calculation of water pool depth

The water pool depth is calculated from the instantaneous rut depth output and output from a horizon sensing gyro according to the figure below:

![Fig. 6](image)

Cross fall deviation

The lateral acceleration and the speed are used for calculation of the curve radius. The cross fall measured in the curve is compared with the specified standard.

Recording ocular inspection

Possibilities are built into the Remote Control Panel to record such observations as:

1. cracks
2. wear
3. patching
4. settlement of shoulder edges
Use of the Saab Road Surface Tester

Depending upon the present purpose of the measurement the Saab Road Surface Tester can be set in any of three automatically controlled modes:

- Mode 1: survey
- Mode 2: contracting
- Mode 3: follow-up

The selection is made by a MODE SELECTOR on the control panel (Fig 3). Data defining: Date/County/Road number/Direction/Lane etc., can all easily be fed into the computer from the control panel keyboard.

**SURVEYING - MODE 1**

![Surveying Mode Diagram](image)

**Fig. 7**

Mode 1

Pre-programmed data recording of measured values, the results being printed and/or tape recorded in a mode adapted for decision making. The tapes are also useful for long-range planning e.g. a road data bank.

Variables: BFC, rolling resistance, evenness and cross profile

Observations: Cracking, patching, wear, shoulder subsidence

Measuring speed: 30-70 km/h; capacity 250-400 km/day

Output: Printer/plotter (Fig. 8)

Information for future use is also recorded on magnetic tape.
Mode 2

Mode 2 implies pre-programmed recording of measured data required for contracting. Computer results such as Estimated Rut Volumes can, e.g., serve as a basis for regional contracting.

**CONTRACTING - MODE 2**

**SPEED RANGE**

**WEAK SECTION**

**ESTIMATED RUT VOLUME PER OBJECT AND PER 400 m-INTERVALS**

**Fig. 9**

**Measuring parameters — estimated rut volume:**

Vol 1 — Covers rut depth in excess of 10 mm

Vol 2 — Restores original surface evenness

Vol 3 — Same characteristics as in Vol 2 plus restoration of original cross fall

**Measuring Speed:** 30-70 km/h

**Output:** Printer/plotter (Fig. 10)

**Fig. 10**
Mode 3

This mode is not pre-programmed, which permits recording of any optional variable, the purpose being to follow-up and check repair work and perform special studies of isolated variables.

**FOLLOW-UP-MODE 3**

**DETAILED KNOWLEDGE OF PARTICULAR PARAMETERS**

**ACTUAL ROAD SERVICE LEVEL**

- FRICITION/WINTER ROAD MAINTENANCE
- EVENNESS/SPRING THAW

---

**Fig. 11**

Measured variables: optional e.g. BFC (wet or dry), cross profile, evenness, rolling resistance, curve radius etc.

Measuring speed: 30-120 km/h depending upon parameter chosen.

Output: Printer/plotter (Fig. 12)

---

**Fig. 12**
Check and Calibration

Checking system

The Saab Road Surface Tester has a built-in self checking system for printer, indicator lamps, computer and power supply.

<table>
<thead>
<tr>
<th>BUILT-IN SELF CHECKING SYSTEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Printer</td>
</tr>
<tr>
<td>- Control lamps</td>
</tr>
<tr>
<td>- Computer</td>
</tr>
<tr>
<td>- Tape recorder</td>
</tr>
<tr>
<td>- Power supply</td>
</tr>
</tbody>
</table>

APPROVED CHECK SHOWS 'GO' ON DISPLAY PANEL

UNAPPROVED CHECK SHOWS FAULT AND LOCATION

Calibration

The Saab Road Surface Tester is equipped with a means for fast and easy field calibration which, including built-in self calibration, has to be activated in conjunction with general overhaul.

The Saab Road Surface Tester is a flexible system which can be adapted to various customers' specific requirements.
Cooperative Project

The development of the Saab Road Surface Tester is a cooperative project initiated and managed by the Swedish Road Administration. The work is being carried out in cooperation with the Swedish Road and Traffic Research Institute and the Aerospace and Saab Car Divisions of Saab-Scania, who is responsible for the technical development of the hardware.
Appendix C

Non-contacting Optoelectronic Displacement Transducer as manufactured by Selective Electronic Inc.
PRECISION NON-CONTACT MEASUREMENT IS SIMPLER THAN YOU THINK.
**OPTOCATOR** IS EASY TO USE. ITS CONCEPT IS SIMPLE. ITS PERFORMANCE IS SOPHISTICATED.

The OPTOCATOR utilizes advanced solid state optoelectronic techniques to provide precision measurement data—for position, dimensions, contour, vibration, thickness, etc.—on almost any material regardless of the surface's texture, temperature, or color. Unlike other non-contact systems, OPTOCATOR does not have to be close to the surface being measured, and it is ruggedly built, for demanding service environments.

Continuous precision measurement is accomplished without mirrors, prisms, video imaging devices, or isotope radiation sources. Simple stationary mounting is adequate in most applications.

The OPTOCATOR provides a digital display of the measured variable, and analog and digital signal outputs for remote recorders, displays, or process controls. A microprocessor continuously monitors the measured variable and provides a signal output should the measurements exceed desired upper and/or lower tolerance limits.

**HOW OPTOCATOR'S GAUGING PROBE WORKS.**

The OPTOCATOR System utilizes an infrared light source—either an LED or laser diode—to create an illuminated spot on the surface to be measured. In the majority of applications, the light is beamed perpendicular to the surface. Most materials—whether hot, cold, hard, or soft—will scatter a portion of this light. The OPTOCATOR "sees" a portion of this scattered light on its detector in the same manner that an image would be focused on the back of the human eye. Any variations in the measured surface's position will result in a change of the location of the focused spot's image on the detector. In this manner, the OPTOCATOR measures the point of origin of the scattered light; and hence the distance to the surface being measured.

Its unique optoelectronic detector is the key to OPTOCATOR's ability to measure minute changes in position. The detector is a new photosensitive device which responds to the location of a spot of light focused on its surface. It detects the center of the light image and generates output signals which are converted into precise position information.

The light source is controlled to maintain a constant intensity on the detector surface. This

*™ Trademark of Selective Electronic.*
feature permits wide variations in the measured surface's reflectivity—texture, color, etc.—without affecting the measurement data. The system rejects any influence from ambient or background lighting.

**USE OPTOCATOR FOR DIMENSION MEASUREMENT.**

Its non-contacting precision measuring capability, coupled with its high frequency response, make OPTOCATOR an ideal instrument for production-line gauging, especially where 100% gauging of high volume items is required. The reference plane does not need to be fixed or stationary. For example, if you wish to measure the height of parts on a moving, vibrating conveyor, a second gauging probe head would be added to measure the position of the conveyor belt surface. The signal processor would compare the signals from the two probes and give an output which is the measurement of the dimension of the part.

**USE OPTOCATOR FOR THICKNESS MEASUREMENT.**

By measuring the surface position of opposite sides of an object, the OPTOCATOR can measure the thickness. The material being measured can be moving past the gauging probe at very high surface speeds and can be vibrating along the axis of measurement. The only requirement is that the surfaces being measured stay within the measuring ranges of the individual gauging probes. This makes the OPTOCATOR ideal for measuring thickness of materials manufactured in a continuous process, such as rolled or extruded metals, plastics, rubber, or food products. Because the system continuously regulates the light source intensity, variations in the texture or color of the surface being measured will not affect the output data.

**USE OPTOCATOR FOR VIBRATION OR DISPLACEMENT MEASUREMENT.**

High frequency response capability makes the OPTOCATOR well suited for many vibration measurement applications, as a non-contacting measuring alternative to other physical methods such as contacting probes or accelerometers.

**USE THE GAUGING PROBE WITH YOUR SYSTEM.**

The standard gauging probe head contains the system’s light source, optoelectronic detector, and signal conditioning electronic amplifiers. It provides a linear signal in a serial digital format.

The light source control circuitry is also incorporated into the gauging probe. This enables the user or OEM with the proper signal processing electronics to use the gauging probe as a “stand alone” item.

**USE A CHOICE OF SIGNAL PROCESSORS.**

The signal from the gauging probe is in a serial digital format. Selcom will provide signal processors that accept the signals from the probe and convert them into both an analog DC voltage signal and a TTL compatible, digital signal for computer interfacing. The signal processor also provides digital display of the measured variable in either metric or English units.

Where it is necessary to monitor for an “out of tolerance” condition, the internal microprocessor continuously compares the measured variables with selected maximum and minimum limits.

In addition to signals indicating an out-of-tolerance condition, separate output signals are provided for an “early warning” that the measured variables have exceeded a selected percentage of the tolerances.

Nominal set-point value, maximum or minimum tolerances, and the selected percentage of the tolerances for the early warning signal, are set into the system by convenient thumbwheel switches on the processor's panel.
**OPTOCATOR ADVANTAGES**
- Rugged design
- Compact cast aluminum housing for stability
- Provision for air cooling and lens protection
- Non-contacting
- Insensitive to ambient light
- Insensitive to surface reflectivity
- High precision
- Automatic calibration with memory
- Fast response
- Measuring ranges to over 250 mm (10 inches)—each gauging probe
- Analog and digital output signals
- Low power requirement

**SPECIFICATIONS**

<table>
<thead>
<tr>
<th>Specifications</th>
<th>8</th>
<th>16</th>
<th>32</th>
<th>64</th>
<th>128</th>
<th>256 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measuring Ranges:</td>
<td>.3</td>
<td>.6</td>
<td>1.25</td>
<td>2.5</td>
<td>5.0</td>
<td>10.0 in.</td>
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<tr>
<td>Standoff distance:</td>
<td>100 mm (4 in.) to 300 mm (12 in.)</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Accuracy:</td>
<td>±0.05% of measuring range—each probe</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Resolution:</td>
<td>0.025% of measuring range</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Linearity:</td>
<td>±0.05% of measuring range—each probe</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Frequency Response:</td>
<td>Up to 2 kHz</td>
<td></td>
<td></td>
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<tr>
<td>Step Response:</td>
<td>Down to 0.175 milliseconds</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Signal Outputs:</td>
<td>Analog 5VDC Digital 16 bit TTL compatible</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light Source:</td>
<td>Infrared LED or laser diode</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max Light Source Power:</td>
<td>&lt;5 milliwatts</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Power requirements:</td>
<td>100/115/230 VAC ±5%. 50/60 Hz</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Gauging probe</th>
<th>Signal processor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length:</td>
<td>450 mm (17.75 in.)</td>
<td>483 mm (19.00 in.)</td>
</tr>
<tr>
<td>Height:</td>
<td>80 mm (3.15 in.)</td>
<td>266 mm (10.50 in.)</td>
</tr>
<tr>
<td>Width:</td>
<td>180 mm (7.10 in.)</td>
<td>273 mm (10.75 in.)</td>
</tr>
<tr>
<td>Weight:</td>
<td>5.5 kg (12.10 lbs.)</td>
<td>5.0 kg (11.00 lbs.)</td>
</tr>
</tbody>
</table>

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Telex: 802-055

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*Federal regulations have been adopted to protect the public from the dangers of electronic radiation. This product complies with the standards relating to laser products as set forth by the Bureau of Radiological Health in 21CFR, sub-chapter J.*