Automated Pavement Evaluation Using Photogrammetry and Remote Sensing

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INTRODUCTION

Wherever there is aging pavement, increasing traffic volumes and truck weights necessitates urgent renovation. Evaluation of pavement conditions is critical in such renovation work. Information must be gathered about the surface of the road, the structural strength of the material used in the pavement and roadbed construction so that a proper maintainance and rehabilitation schedule can be developed. In the past such information was gathered manually by road crews. With the advent of computers and the development of technology this information-gathering process can be fully automated.

The Iowa DOT obtain information on cracking, patching and rut depth from road crews who measure these aspects of road conditions manually in accordance with procedures developed by the AASHO road test in Illinois in the 1950's. Roughness is measured with a BPR or IJK roadmeter type profilometer which is calibrated against the chole profilometer.

PASCO USA, Inc. has developed a fully automated system to give the surface condition information. The extent of cracking and patching of road surface is determined by using continuous strips of photographs taken at night with a slit camera. The rut depth is deterined when a hairline is projected at an angle and the projected image is photographed by a pulse camera. Roughness is measured by the three non-contact Ga-AS diode laser sensors.

At Iowa State University (ISU) research was conducted to study current methods used by the Iowa Department of Transportation (IaDOT) to evaluate pavements and the automated pavement evaluation techinique developed by PASCO USA, Inc. (a subsidiary of PASCO Japan, Inc.)

The objective of this paper are:

(a) to describe briefly the systems used by Ia DOT and PASCO

(b) to give the results of the experiments conducted by ISU to evaluate the two systems

(c) to present recommendations for using photogrammetry and remote sensing techniques in pavement evaluations.

Description of the Iowa DOT Method

The Iowa DOT defines the present serviceability index (PSI) of a road surface as

$$PSI = LPV - 0.01 (C_{AC} + P)^{1/2} - 1.3 (RD)^2$$

for an asphalt surface and

$$PSI = LPV - 0.09 (C_{PC} + P)^{1/2}$$

for concrete surfaces, where:

LPV is a function of the roughness of the road

C_{AC} is the number of square feet per 100 square feet of asphaltic concrete exhibiting cracking

C_{PC} is the number of square feet per 1000 square feet of portland cement pavement

P is the number of square feet per 1000 square feet of asphaltic concrete pavement exhibiting "alligator" or fatigue cracking

RD is the mean depth of rutting, in inches, measured with a four foot straight edge.

Thus, the PSI is made up of two values- the LPV and the deduction for cracking, patching and rut depth. The LPV is selected so that the maximum LPV is five when the roughness is zero. Thus, the PSI value can range between zero and five: five indicating excellent and zero indicating poor road conditions.

ROUGHNESS

Roughness can be defined as the deviation of the surface from a smooth profile, a constant gradient longitudinal profile. The Iowa DOT uses the Bureau of Public Roads (BPR) roughometer to obtain the roughness in terms of inches of roughness per mile. The BPR consists of a single road wheel attached to an accumulating counter by a one-way clutch (see fig.1). As the wheel moves up and down while being towed, all movements in one direction are summed. Another counter records the number of revolutions of the tire so that distance travelled can be calculated. The BPR readings are calibrated against a standard roughometer, CHOLE, to give the LPVs.

CRACKING, PATCHING AND RUT DEPTH

The Iowa DOT uses crews of three to five persons to observe and record the extent of cracking, patching and rut depth. The crew drives on the shoulder if possible, estimates the areas of cracking and patching, and records them on a work sheet. The rut depth is measured at every 0.05 miles for asphalt pavement, and

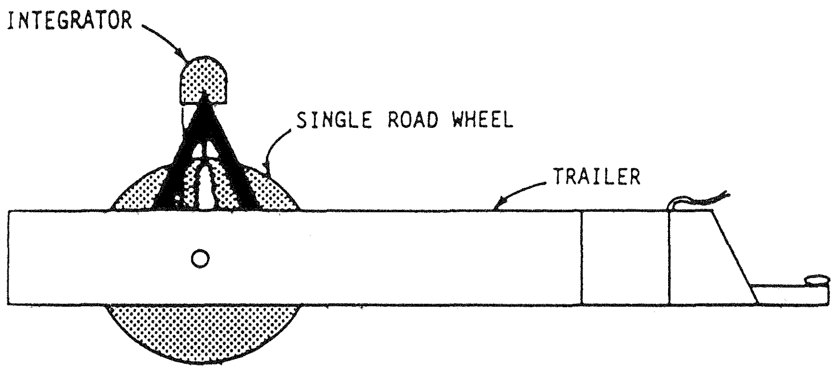

Fig.1 . BPR method.

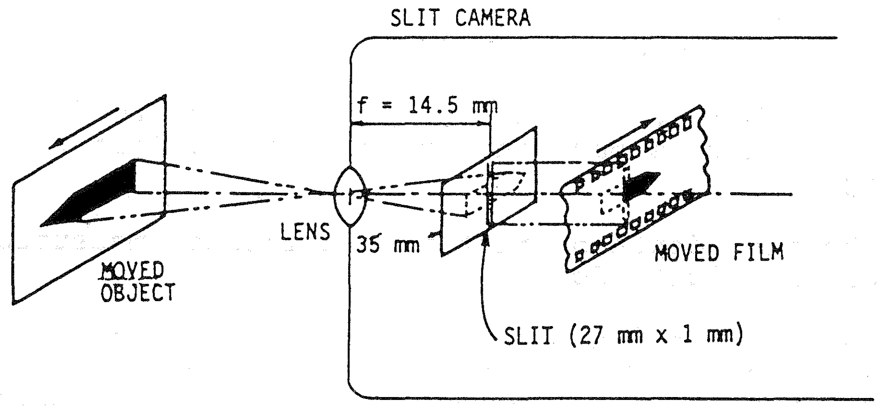

Fig. .2. Slit camera.

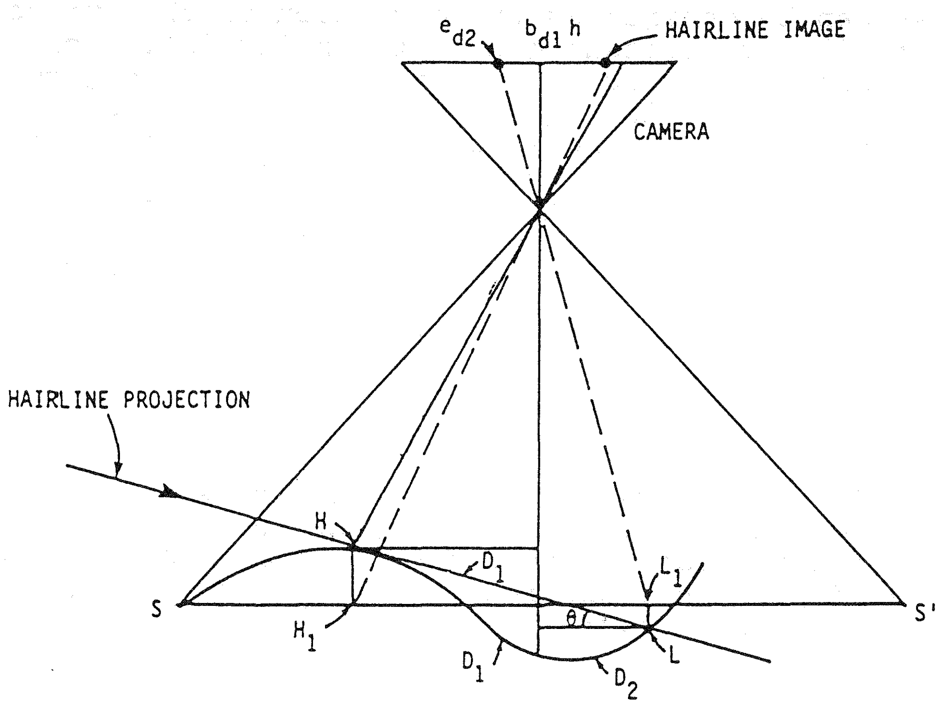

Fig.3 . ROADRECON-75.

one set of readings is taken at the beginning and end of a half-mile section of concrete pavement.

Description of PASCO Method

The objective of the PASCO method is to determine the values of cracking, patching, rut depth and roughness so that the present condition of the road can be evaluated and the future condition predicted. The PASCO method computes a Maintainance Control Index (MCI) from the equation

$$MCI = 10 - 1.48\ CR^{0.3} - 0.29\ RD^{0.7} - 0.47\ SD^{2}$$

OR

$$= 10 - 1.51\ CR^{0.3} - 0.30\ RD^{0.7} \quad \text{(if roughness is not available)}$$

OR

$$= 10 - 2.23\ CR^{0.3} \quad \text{(using only the cracking ratio)}$$

OR

$$= 10 - 0.54 RD^{0.7} \quad \text{(using only rut depth)}$$

Thus, MCI varies from 0 (poor) to 10 (very good). PASCO uses the Roadsecon -70, a 35 mm slit camera, to take continuous photographs of the road and then to interpret the photograph and measure the area to obtain CR. The RD is measured on the photograph of a hairline projected at an angle taken by a pulse camera, Roadrecon -75. The longitudinal roughness (SD) is measured either by Roadrecon -77 or Roadrecon 85. TRhe Roadrecon -77 system uses a tracking wheel fitted with a differential transformer and a servo accelerometer to measure roughness, whereas the Roadrecon 85 uses three non-contact GA-AS diode laser sensors to measure profile and roughness.

Slit Camera: The RoadRecon -70

The Roadrecon -70 system uses a 35 mm slit camera to obtain continuous strip photography of the driving lane. The camera's slit aperture is 1.08 in (27 mm) long and can vary in width from 0.004 in to 0.04 in (0.1 mm to 1.0 mm). The lens has a focal length of 0.58 in (14.5 mm) with F/3.5. (see fig. 2)

The camera is mounted on a boom on top of the Survey vehicle, about 2.9 m above the ground. This set up results is a photographic scale of 1: 200. Since the slit length is about 1.08 in (27mm), the photographs cover over 5m of road width. The film speed and camera aperture size are synchronous with the vehicle speed to produce a continuous strip of photographs. This system can be operated at speeds between 44 and 55 mph (70 and 80 km/h). The system, which can operate day or night, uses a bank of 10 halogen lamps mounted under the bumper for constant illumination.

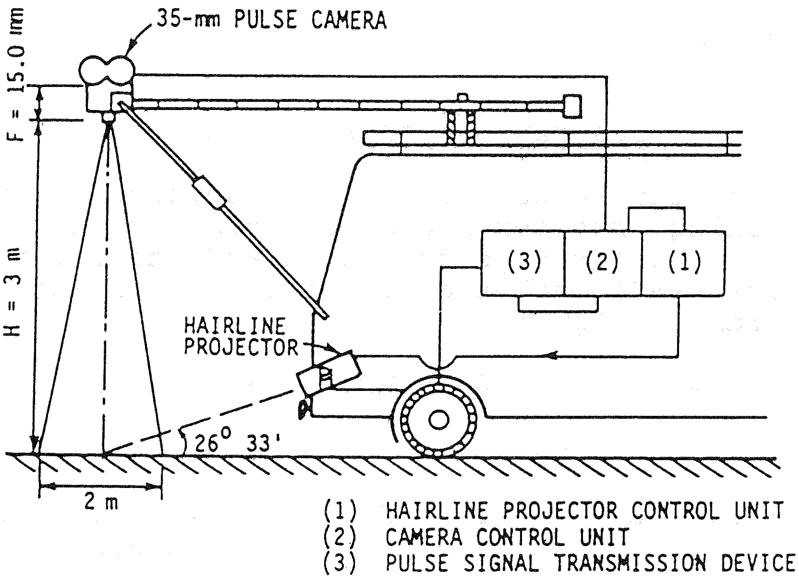

Fig.4 . ROADRECON-75 for rutting survey.

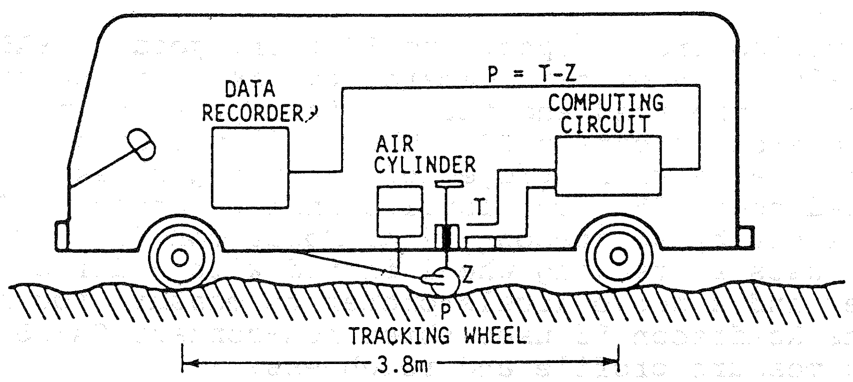

Fig. 5 . ROADRECON-77 for evenness survey.

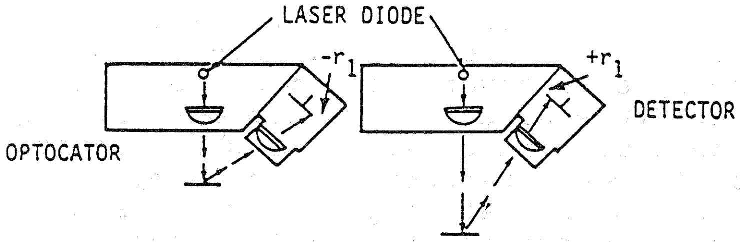

Fig. 6 Laser reflection.

The processed positive film is projected at ten times enlargement onto an electronic digitizer. A key is used to interpret the projected image, subsection by subsection for cracks and patches. The area of the interpreted patches and cracks is measured by the grid cell system.

Pulse Camera: The Roadrecon-75

The Roadrecon-75 uses a 35 mm pulse camera and a hairline projection strobe light to photograph rutting wave patterns. Fig 3 shows the image location of a hairline projection on the longitudinal profile of raod by a vcertical camera. Suppose the hairline at H is imaged at h and the hairline at L is imaged at l, then,

$$D_1 = \frac{Ho}{f} d_1$$

$$D_2 = \frac{Ho}{f} d_2$$

where,

f = focal length of the camera
Ho = height of camera above mean ground
D_1, D_2 = ground distance
d_1, d_2 = image distance

The rut height $= HH_1 = D_1 \tan 0$
The rut depth $= LL_1 = D_2 \tan 0$

Therefore, the total rut depth RD $= (D_1 + D_2). \tan 0$

$$= \frac{H}{f}(d_1 + d_2).\tan 0$$

$$= S \tan 0 \, (d_1 + d_2)$$

where,

S = the scale of the photo

In the Roadrecon-75 system the strobe light is mounted on the bumper of the survey vehicle and projects the hairline at an angle 0 = 26 33' such that tan 0 = 1/2. The camera , mounted on a boom onm top of the vehicle, photographs the line in which the vehicle is driving, see fig 4. The focal length of the camera, f = 0.6 in (15 mm), and the height of the camera above the ground, Ho = 120 in. (3000 mm), result in a scale for the photograph of S=200. Thus, the toal rut depth = $200(d_1+d_2)/2$, and if d_1 and d_2 are measured to an accuracy of + 0.0002 inches (= 0.005mm) by digitizing a ten time enlargement projection, the rut depth RD can be determined to an accuracy of + 0.04m (+ 1mm).

This system can operate only at night at speeds between 0 and 50 mph (80 km/h). Both the strobe light and the camera shutter are triggered at given intervals of pavement travel.

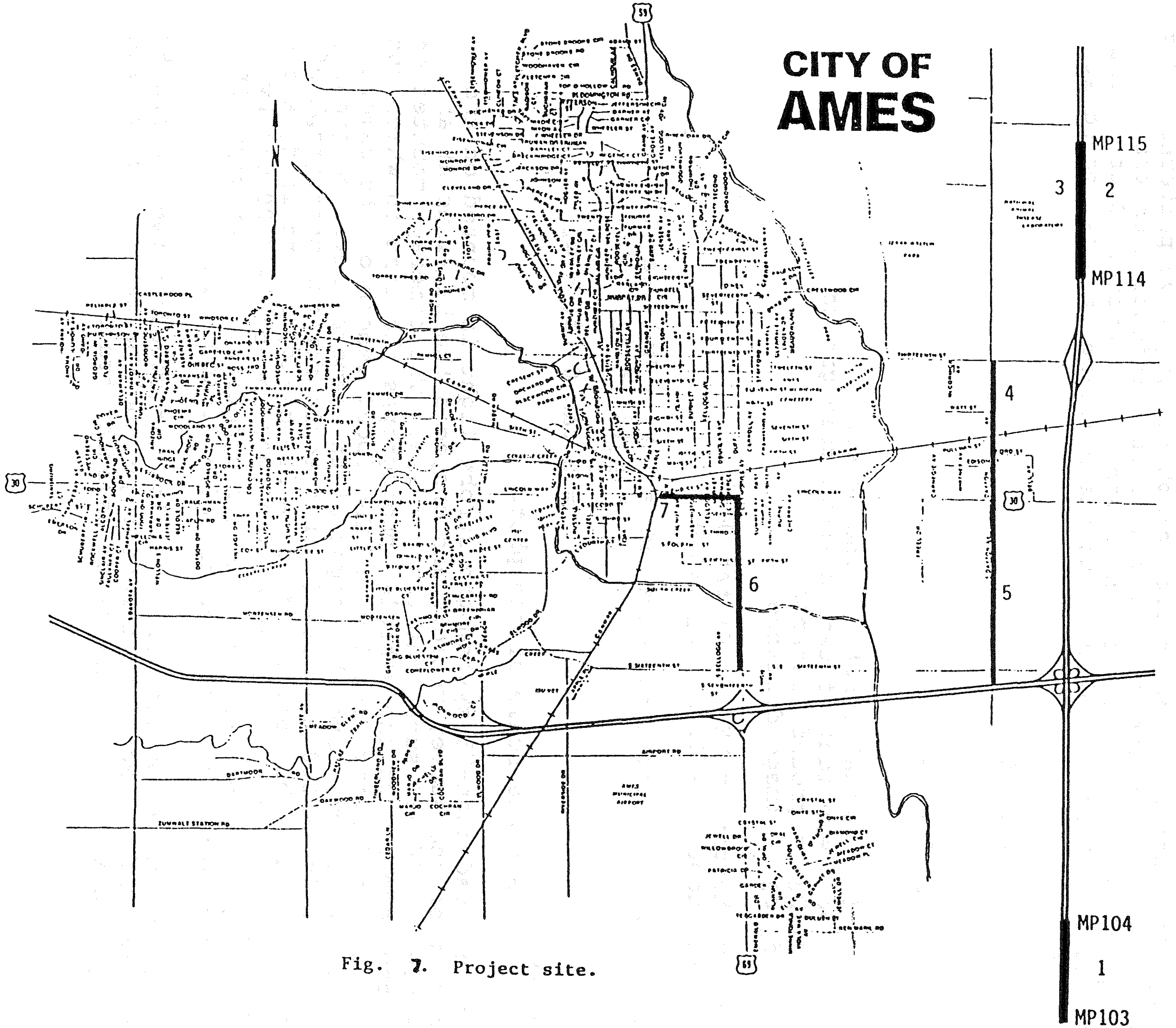

Fig. 7. Project site.

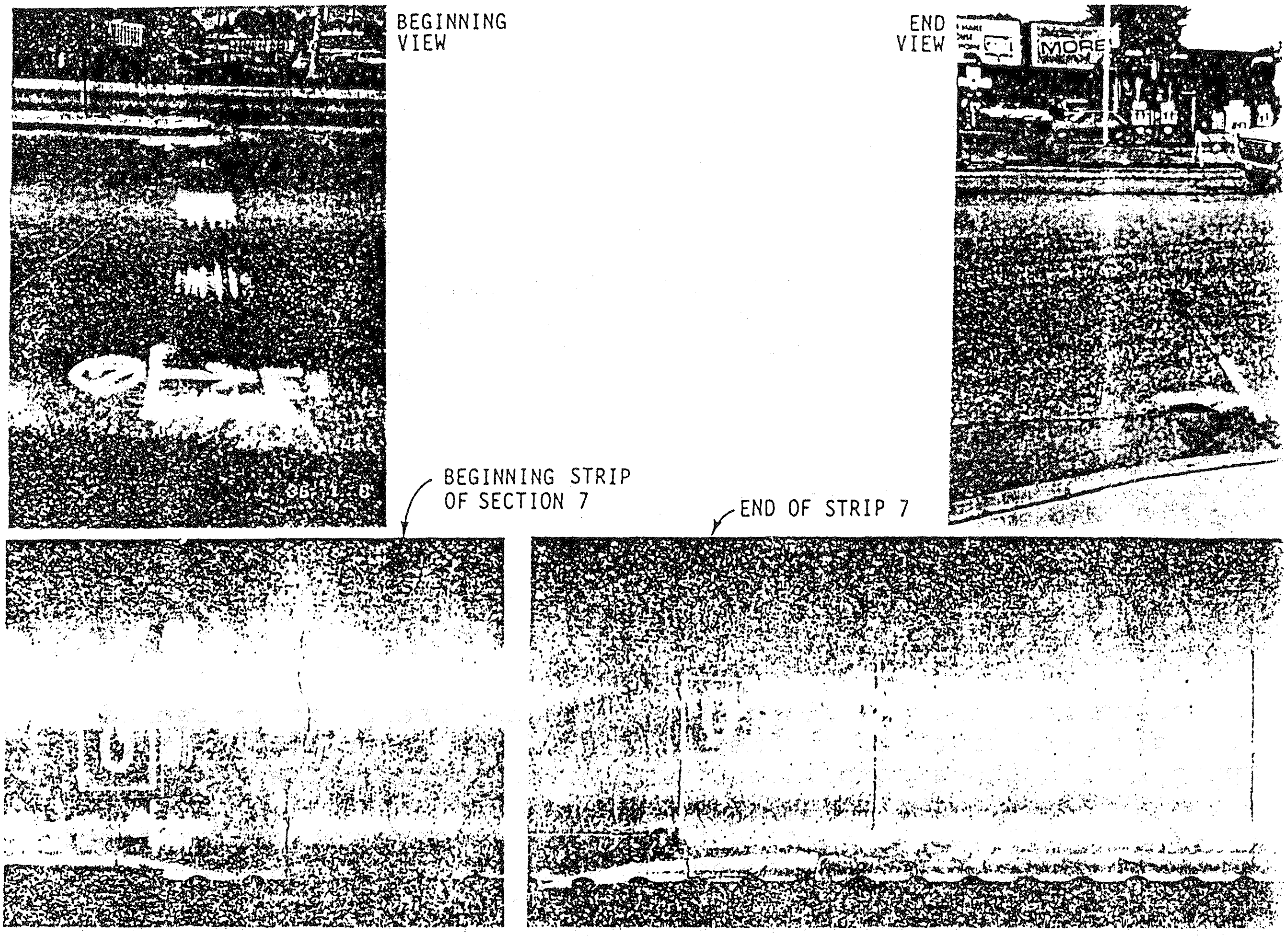

Fig. 8 . Continuous strip photograph.

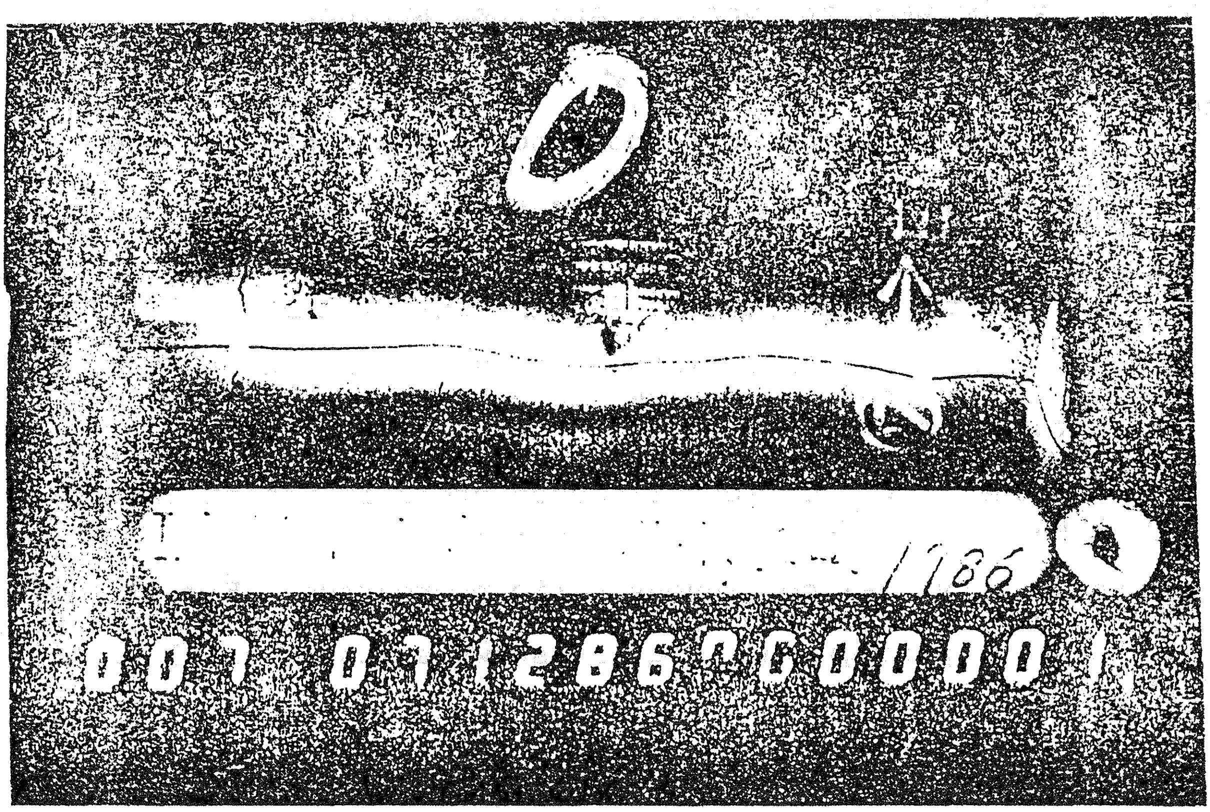

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Fig. 9 Pulse photograph.

Tracking Wheel- The Roadrecon-77

The Roadrecon-77 uses a tracking wheel to measure longitudinal roughnesas of a road surface. The roughness is measured by a differential transformaer anf a servo accelerometer attached to the tracking wheel. The tracking wheel is arranged so that it measures the roughness in the right wheel track of the lane in which the survey vehicle is driving. (see fig 5). The accelerometer, attached to the tracking wheel or the profile detector, measures the vertical acceleration and feeds the information to an on-board computer. The computer performs the necessary integration to determine the vertical displacement. The Roadrecon -77 can operate day or night at speeds between 0 and 40 mph.

Laser- THe Roadrecon-85B

The Roadrecon- 85B uses three non-contact GA-AS diode laser sensors to measure roughness. The lasers are mounted on the bumpers of the survey vehicle, one over each wheel and one centered between them.

As the vehicle travels along the road, the lasers are triggered at a given interval of pavement travel. The laser diode, in the Optocator, emits a nonparallel beam of invisible infra-red(IR) light via a lens system. The laser beam triggered at a particular instant hits the surface of the road, and the diffused or scattered beam enters the detector via a lens system (see fig 6). The lens of the detector focuses a spot image on a unique semi-conductor, an analog linaer position detector. Here, the controllers for the non-contact laser measure the distance, r, of the spot image from the center of the detector anf the computer distance, x, between the vehicle and road surface

$$X = Xo \pm r$$

where,

Xo is the distance corresponding to the center of the detector.

The variation in X gives the roughness of the ride.

Comparison of PASCO and Iowa DOT Methods

In order to judge the PASCO method of evaluating the surface condition of the road, it was decided to survey the surface of seven sections, each approximately one mile in length (see fig.7). The sites represent the various pavement and traffic conditions that Iowa DOT actually encounters in rehabilitating and maintaining the primary road system.

Fig.8 shows a typical continuous strip photograph. Fig. 9 shows a pulse photograph and fig. 10 shows a typical cross section plot from the pulse photograph. Fig. 11 shows a longitudinal profile by laser.

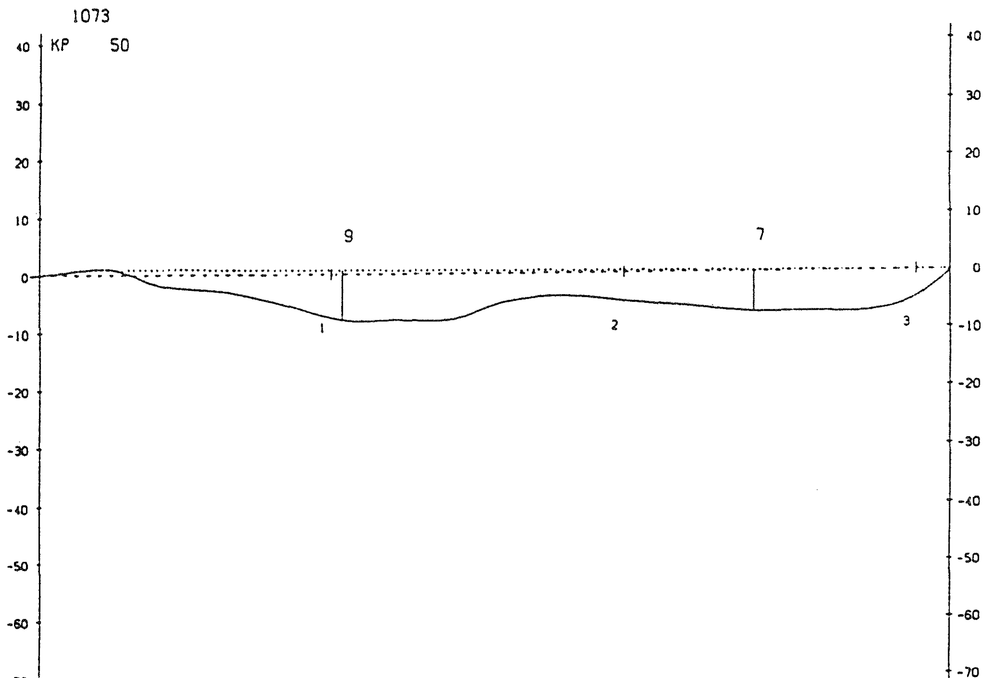

Fig. 10. Cross section of Section 7.

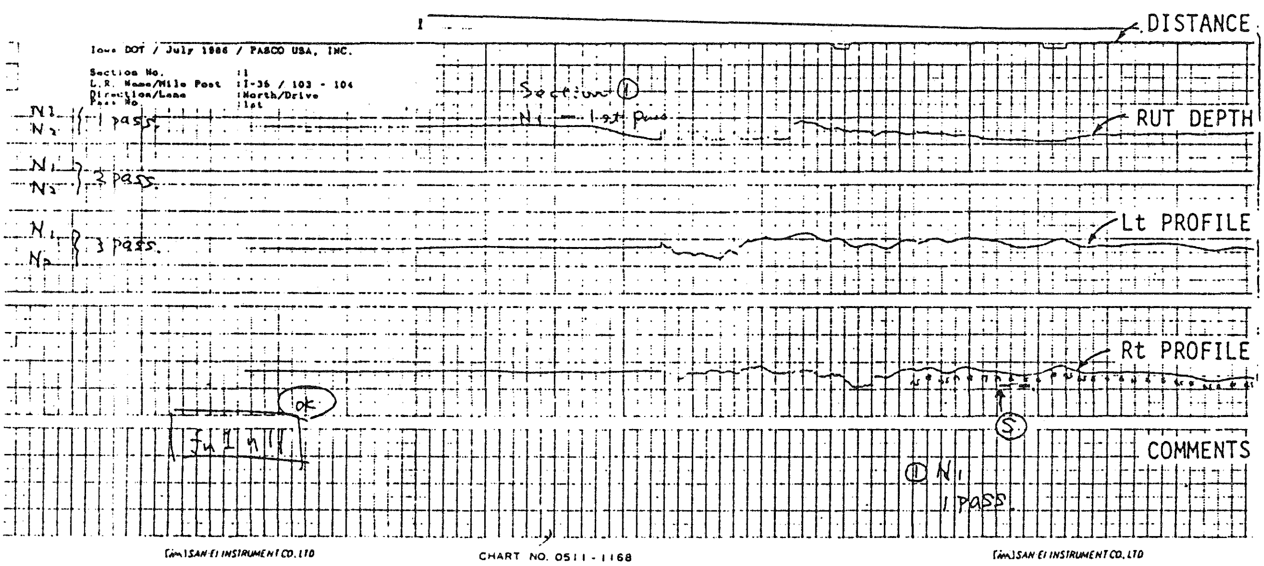

Fig. 11. Longitudinal profile by laser.

Table 1a. Evaluation of automated data collection equipment for determining pavement condition (data table of BPR roughometer and ROADRECON-77) at 25 mph.

Section No.	4		5		6				7			
Legislative Route Name	Dayton Ave.		S. Dayton Ave.		S. Duff Ave.				Lincoln Way			
Section Length (mile post)	0.8 mi		1.01 mi		0.839 mi				0.530 mi			
Pavement Type	Asphalt		Concrete		Concrete/Asphalt				Concrete			
Direction	North	South	North	South	North		South		West		East	
Lane ID	DR[1]	DR	DR	DR	DR	PA[2]	DR	PA	DR	PA	DR	PA
1. TCR[3] (in/mile) based on BPR												
1st pass	144	137	127	,140	173	129	120	108	204	186	190	170
2. SD[4] (mm) based on ROADRECON 77												
1st pass	2.3	2.7	2.5	2.4	4.5	2.9	2.5	2.4	5.8	5.0	5.2	4.1
2nd pass	2.4	---	2.6	---	4.6	3.1	2.8	2.4	5.6	4.7	---	3.8
3rd pass	2.4	2.8	2.6	2.4	4.7	3.2	3.0	2.3	5.8	4.9	5.4	3.8
3. TCR (in/mile) based on ROADRECON 77												
1st pass	161	190	166	163	284	196	170	166	399	388	400	326
2nd pass	168	---	172	---	287	207	181	169	380	366	---	311
3rd pass	163	192	174	161	292	207	198	159	391	381	405	303
4. SD (mm) based on ROADRECON 85B												
1st pass	---	---	---	---	8.5	---	8.1	---	---	---	---	---
2nd pass	---	---	---	---	9.0	---	7.5	---	---	---	---	---
3rd pass	---	---	---	---	8.4	---	7.3	---	---	---	---	---
5. TCR (in/mile) based on ROADRECON 85B												
1st pass	---	---	---	---	301	---	256	---	---	---	---	---
2nd pass	---	---	---	---	287	---	193	---	---	---	---	---
3rd pass	---	---	---	---	210	---	170	---	---	---	---	---

[1]DR = Driving lane

[2]PA = Passing lane

[3]TCR = Total cumulative roughness

[4]SD = Standard deviation (longitudinal roughness)

Table 1b. Evaluation of automated data collection equipment for determining pavement condition (data table of BPR and ROADRECON-85B) at 40 mph.

Section no.	1		2		3		6*	
Legislative route name	I-35		I-35		I-35		S. Duff Ave.	
Section length (mile post)	1 mi (103 - 104)		1 mi (114 - 115)		1 mi (115 - 114)		0.839 mi	
Pavement type	Concrete		Concrete		Asphalt		Co/As	
Direction	North		North		South		North	South
Lane ID	DR	PA	DR	PA	DR	PA	DR	DR
1. TCR(in./mile) based on BPR								
1st pass	77	76	76	75	78	85	173	120
2. SD(mm) based on ROADRECON-85B								
1st pass	6.0	5.7	5.8	5.5	5.2	4.6	8.5	8.1
2nd pass	6.2	5.5	4.5	4.7	4.3	4.3	9.0	7.5
3rd pass	6.5	6.1	4.5	5.3	4.0	3.8	8.4	7.3
3. TCR(in./mile) based on ROADRECON-85B								
1st pass	162	140	131	130	115	105	301	256
2nd pass	165	142	99	118	92	93	287	193
3rd pass	164	147	118	122	89	82	210	170

*At 25 mph.

Table 12. Average rut depth (inches). / ∠

Section	PASCO	Iowa DOT
1	0.22	0.09
2	0.20	0.025
2Sh[1]	0.15	0.02
3P[2]	0.31	0.06
3A[3]	0.14	0.02
3PSh	0.70	0.11
3ASh	0.13	0.0
4	0.24	0.105
5	0.24	0.007
6N[4]	0.33	0.15
6S[5]	0.35	0.14
7W[6]	0.20	0.02
7E[7]	0.18	0.04

Iowa DOT vs PASCO Results:

Number of data = 13
Intercept = +0.0046
t = 2.57
Slope = +0.2144
Correlation coefficient r = 0.6137
Goodness of fit r^2 = 0.0367

Table 3. Cracks (square feet) per 1000 square feet pavement.

Section	PASCO	Iowa DOT
1	9.775	2.275
2	0.25	0.09
2Sh[1]	13.5	0
3P[2]	264.9	12.78
3A[3]	0.03	0
3PSh	0.25	0
3ASh	1.36	0
[4	143.4	275]
5	0.25	0
6NA[4]	329.92	24.35
6NP	3.32	24.35
6SA[5]	290.92	3.64
6SP	8.21	3.64
7W[6]	83.69	36.17
7E[7]	68.57	35.61

Iowa DOT vs PASCO Results:

Number of data = 15
Intercept = +18.1579
Slope = +0.1195
Correlation coefficient
r = 0.2036
Goodness of fit r^2 = 0.0414

With the bracketed pair omitted:

Number of data = 14
Intercept = +7.3827
Slope = +0.0368
Correlation coefficient
r = 0.3235
Goodness of fit r^2 = 0.1047
t = 1.18

[1]Sh = Shoulder

[2]P = Portland cement

[3]A = Asphalt

[4]N = North

Table 4. Area of patches (square feet) per 1000 square feet pavement.

Section	PASCO	Iowa DOT
1	14	0.16
2	5	0
2Sh[1]	53.75	0
3P[2]	1	8.05
3A[3]	7	0
[3PSh	11.25	692.7]
3ASh	0	0
4	1.7	0
5	1	0
6NA[4]	14.74	12.97
6NP	0.55	12.97
6SA[5]	5.48	4.42
6SP	3.50	4.42
7W[6]	63.65	104.20
7E[7]	27.31	87.17

Iowa DOT vs PASCO Results:

Number of data = 15
Intercept = +51.249
Slope = +0.754
Correlation coefficient r = 0.083
Goodness of fit r^2 = 0.007

With the bracketed pair omitted:

Number of data = 14
Intercept = +1.146
Slope = +1.099
Correlation coefficient r = 0.660
Goodness of fit r^2 = 0.436
t = 3.04

[1]Sh = Shoulder
[2]P = Portland cement
[3]A = Asphalt
[4]N = North
[5]S = South
[6]W = West
[7]E = East

Table 5. PSI and MCI linear regression.

Section	PSI	MCI
1	3.74	6.4
	3.85	7.3
2	3.94	8.3
	3.91	8.1
3	3.37	8.7
	3.33	8.5
	2.79	8.5
4	2.4	4.9
	2.5	5.2
5	2.99	7.8
	3.18	8.1
6	2.47	3.6
	2.29	3.3
	2.70	3.1
	2.79	3.7
7	1.56	3.3
	1.67	3.4
	1.73	4.0
	1.81	4.9

Results:

MCI vs PSI
- Intercept = -0.139
- Slope = +2.145
- Goodness of fit r^2 = 0.579

PSI vs MCI
- Intercept = +1.212
- Slope = +0.270
- Goodness of fit r^2 = 0.579
- n = 19 r = 0.769

Approximate work time: 1 hr.

$$t = \frac{R^2(n - 2)}{1 - R^2}$$

$$= 48$$

So that the two systems could be compared, it was decided to convert the PASCO results to the scale and units of Iowa DOT.

Table 1a and 1b show the comparisons of the roughness. The correlation between Iowa DOT versus PASCO (77) was about .93; for Iowa DOT versus PASCO 85B, it was about 0.84. The correlation for the laser is low because of insufficient data, and perhaps also because of multiple reflection of the laser beam.

Table 2 shows the comparisons of the rut depth measurement by PASCO system and Iowa DOT. The low correlation, of 0.61, probably results from Pasco using the shoulder of the pavement as a reference to measure the rut depth, whereas Iowa DOT uses a four foot rod across the rut to measure the depth.

Table 3 shows the comparisons of cracks by the two methods. The low correlation of 0.32 is probably due to the fact that the PASCO method included hairline cracks, whereas the Iowa DOT method used only large cracks visible to an observer.

Table 4 shows the patch comparison. The correlation was found to be 0.66. Table 5 shows the PSI and MCI comparison. The correlation between the two is 0.77.

Conclusions and Recommendations

The slit and the pulse cameras of the PASCO system appear to be a definite improvement over the Iowa DOT system for the measurement of cracking and patching.

The laser system, a non-contact system, does not appear to be fully developed. Upon its satisfactory development, it has the potential of replacing BPR presently used by Iowa DOT.

It is recommended that the PASCO system be modified to allow the simultaneous operation of the pulse camera, slit camera and the laser. This modification will not only allow simultaneous data collection but will also help in precisely locating the position of the pulse camera exposure.

The data collected by laser can be made compatible with a personal computer such as IBM-PC. The data can then be easily analyzed in the office.

The slit photograph can be digitized so that image analysis technique can be used to automate the computation of patching and cracking areas.

The PASCO system can be equipped with a GPS navigator which will enable to precisely locate the position of the slit camera exposure, as well as create DTM data for the road surface. The DTM data can be used to update raod maps and in redesigning roads etc.