Performance of a Sensitivity Analysis on the Multi-Function Network Survey Vehicle (MFNSV)

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Abstract: Multi-Function Network Survey Vehicle (MFNSV) provides cutting-edge technology for obtaining highway pavement information such as; roughness, rutting, geometric data, road condition data as images and accurate distance measurements. The Hawkeye processing toolkit is used to process the data collected through a moving vehicle. The MFNSV manufacturer claims that the information is fairly accurate when the vehicle is driven within a speed range of 20 to 110 km/h.

Road pavement information was collected manually through accurate field measurements along 4 sample stretches on the A004 road, and the same information was collected through the MFNSV. The results obtained from the two methods were compared by carrying-out a sensitivity analysis test. The results of the sensitivity analysis showed that the information collected from all 4 sample test sites did not possess significant statistical differences between the data collected by the two methods.

Keywords: Pavement Failure Inspection, MFNS Vehicle, Sensitivity Analysis

1. Introduction

It was intended to conduct a sensitivity check on the Multi-Function Network Survey Vehicle (MFNSV) (see Figure 1) which provides cutting-edge technology for obtaining highway pavement information under local conditions. Data collected through the MFNSV is processed through the Hawkeye 2000 package installed on the MFNS vehicle. This study was possible due to the assistance rendered by the Planning Division of the Road Development Authority of Sri Lanka which presently uses the MFNSV for its highway pavement data collection operations. Sample data was collected manually as well as through the MFNSV and results were compared and differences were statistically checked.

According to the manufacturer, the following are some of the general applications of MFNSV [1]:

- Network and project level road and asset collection surveys
- Routine pavement monitoring surveys
- Roadside inventory and asset management
- Road geometry and mapping surveys
- Contractor quality control
- Road safety assessment
- Line marking reflectivity
- Airport runway inspections

Highway pavement information listed below was collected from the sample sites through manual surveys as well as from the MFNSV.

1. Crack areas (all types of cracks)
2. Defected patch areas
3. Ravelling areas
4. Pot-hole areas
5. Lane width

Thereafter samples obtained were compared with one another using statistical techniques and the differences were observed.

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2. Methodology

As already mentioned, Manual Data Collection and MFNS Vehicle Data Collection were carried-out at four selected road sections.

Manual Road Inspection

Under this method, one has to inspect the road visually and collect data manually by measuring each and every type of failures and their magnitude in relation to the chainage and fill the standard visual inspection form (see Appendix A) that was developed for this process.

Field observation data collected through visual inspection forms (i.e., Appendix A) are fed into the computer according to the format shown in Appendix B. The format given in Appendix B includes the chainage of the survey section, surface type, lane width, shoulder type, shoulder width, roughness, serious damages and all other defects, drainage type, drainage condition, road side information and space for any suitable comments. Cracks, serious damages, surface deformation and edge damages are recorded in linear meters. Potholes are recorded as numbers. If the field surveys are conducted by competent persons, the results obtained can be very accurate.

Though this form records the potholes in numbers and other failures in linear meters, to compare with the sensitivity of vehicle data, the areas of those failures had to be measured. If a pothole area was larger than 4 m², it was recorded as a surface deformation. The minimum length of a survey section was 100 m. However in special cases, the inspector had to increase the survey length. This is the most accurate method to inspect the road since it is done manually.

Multi-Functional Network Survey Vehicle (MFNSV)

Figure 1 - Multi-Functional Network Survey Vehicle (MFNSV)

1. Digital Camera
2. Automatic Crack Detector
3. GPS or DGPS
4. GPSI – Track Geometry
5. Rotorpulser
6. Mobile Line Reflectivity
7. LIDAR Asset Detection
8. Data Acquisition System

(Courtesy of Traffic & Planning Division of RDA)

This vehicle is of cutting-edge technology, and includes devices such as five numbers of high resolution digital cameras, a front laser mounting beam, side projection lasers, a rotor-pulser, a data acquisition system, gipsy-track geometry, a GPS (Global Positioning System) and a DGPS (Differential Global Positioning System). Using those devices, details such as roughness, rutting, geometric data and road condition data can be obtained as images and distance measurements. The Hawkeye processing toolkit is used to process the data taken from this vehicle. To obtain accurate readings, the vehicle has to be driven on the road at a speed between 20 km/h and 110 km/h.

Pavement data was collected from four sample stretches each of 200 meter length located on the A004 CRWB (Colombo, Ratnapura, Wellawaya and Batticaloa) road between Meepe and Avissawella. As indicated in Figure 2, four 200 meter stretches from 35 km, 40 km, 45 km and 50 km posts were selected for the data collection.

Failure Types

- Cracks – There are several types of cracks that can be seen on roads. i.e, longitudinal cracks, transverse cracks, diagonal cracks, block cracks and crocodile cracks. All of those cracks can be measured under this category.
- Raveling – This is the removal of materials from the pavement surface.
- Potholes – Potholes are bowl-shaped holes. The distress progresses downwards into the lower layers of the pavement.
- Defected patch areas where the failure of early treated areas as that has taken place.

Measurement of Failures

During manual inspection, all failure areas were measured using steel tapes. In the MFNSV method, all failure areas were measured using the Hawkeye processing toolkit software. The area obtained from the software is presented below.

Figure 2 - Layout of the Study Area

Figure 3 - Crack area from the software

3. Data Analysis and Results

Vehicle inspection survey data was collected to find out the total failure percentages according to each failure type with 200m samples taken at every 5km interval by looking at all pictures of the road using the software. All failure areas identified during vehicle inspection were analysed using the Hawkeye software tool. Its calculation part is shown below. All failure areas identified during manual inspection were measured using steel tapes and the corresponding failure percentages were calculated (Figure 3). Thereafter, the failure percentages were compared and a sensitivity analysis of pavement inspection methods with 200m samples taken at every 5km interval was done. The process followed in obtaining failure percentages of the first section (35 km – 35.2 km) is described below in which only the 35.001 km chainage has been considered for the sample calculation.

In manual inspection,

Crack areas	= 0
Defected patch areas	= 0
Raveling areas = 1.5 x 1.67	= 2.51 m ²
Pothole area	= 0
Lane width	= 3.8 m

In vehicle inspection,

Crack areas	= 0
Defected patch areas	= 0
Raveling areas	= 2.514 m ²
Pothole area	= 0
Lane width	= 3.8 m

$$\text{Failure percentage} = \frac{\text{Total failure area} \times 100\%}{\text{Total area of one section}} \dots (1)$$

Consider the 35.001 km chainage in Table 1 which is shown in APPENDIX B relevant to manual inspection survey results.

Length of one sub section	= 4 m
Width of one sub section	= 3.8 m
Area of one sub section	= 15.2 m ²
Total failure area	= 2.510 m ²
Failure percentage	= $\frac{2.510 \times 100}{15.2}$
	= <u>16.51%</u>

Consider the 35.001 km chainage in Table 1 which is shown in Appendix B Band which relates to visual inspection survey results from the vehicle.

Length of one sub section	= 4 m
Width of one sub section	= 3.8 m
Area of one sub section	= 15.2 m ²
Total failure area	= 2.514 m ²
Failure percentage	= $\frac{2.514 \times 100}{15.2}$
	= <u>16.54%</u>

4. Sensitivity Tests

4.1 Sensitivity Analysis

The vehicle and manual inspection surveys were compared with respect to total failure percentages. Thereafter, the sensitivity of the vehicle was checked through sensitivity analysis. Each 200 m was then divided into 4 m intervals and 50 data sets for manual inspection and 50 data sets for vehicle inspection were obtained for each section. SPSS software was used to check the statistical significance of the test. Results were obtained based on the t-test. For the t-test, both 95% and 99% confidence intervals were used.

Correlation analysis is used to quantify the association between two continuous variables (e.g., between an independent and a dependent variable or between two independent variables). To find the correlation coefficient, the following equation can be used.

$$r = \frac{\sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^n (x_i - \bar{x})^2 \sum_{i=1}^n (y_i - \bar{y})^2}} \dots\dots (2)$$

where,

n = sample size

x_i = independent variable

y_i = dependent variable

Regression analysis is a related technique to assess the relationship between an outcome variable and one or more risk factors or confounding variables.

In regression analysis, the dependent variable is denoted by "y" and the independent variables

by "x". Many techniques for carrying out a regression analysis have been developed.

Linear regression equation as[2]:

$$y_i = ax_i + b \quad \dots (3)$$

where,

$$a = \frac{n \sum_{i=1}^n x_i y_i - \sum_{i=1}^n x \sum_{i=1}^n y}{n \sum_{i=1}^n x^2 - (\sum_{i=1}^n x)^2}$$

$$b = \bar{y} - a\bar{x}$$

$$\text{where, } \bar{x} = \frac{\sum_{i=1}^n x}{n}, \bar{y} = \frac{\sum_{i=1}^n y}{n}$$

Symbol a represents the slope or gradient of the line, and is also sometimes called the regression coefficient while symbol b represents the intercept that is the value of y where the line crosses the y axis.

Null Hypothesis is a statement that the value of the population parameter is no different from that which is equal to a specified value. Statically, a null hypothesis may be stated as;

$$H_0: \mu_1 = \mu_2$$

Where μ_1 and μ_2 are population means.

The Alternative Hypothesis is a statement that there is some difference in the two populations. It can be stated as

$$H_a: \mu_1 \neq \mu_2$$

For our study, manual inspection readings were taken as μ_1 and vehicle inspection readings were taken as μ_2 .

The output taken from the SPSS software is discussed below. It shows that the accuracy of the MFNSV is high.

Figure 4 shows the failure percentages of the first section (35 km- 35.2 km) which were selected for the study. The X axis represents 50 parts while the Y axis represents failure percentages of each part.

Table 1 and 2 represent the tabulations of the mean, standard deviation, standard error mean, confidence interval of the difference, t value, degree of freedom and the significant value of two tailed test for the 95% and 99% confidence intervals respectively.

The paired sample t test results as shown in Table 1 above will appear in the SPSS output window. The p -value is 0.021 and α value is 0.05. The p -value is greater than 0.05 which implies that the hypothesis has not been rejected. Therefore, there is no difference between manual and vehicle readings at 95% confidence level.

Figure 4 – Failure percentages from 35 km – 35.2 km

Table 1 - Paired Samples Test for a 95% confidence interval

Sample Pair		Paired Differences					t test result	Degree of freedom	Significant (2-tailed)
		Mean	Standard Deviation	Standard Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Manual Reading - Vehicle Reading	-0.213	1.288	0.091	-0.392	-0.033	-2.334	199	0.021

Table 2 - Paired Sample Test for a 99% Confidence Interval

Sample Pair		Paired Differences					t test result	Degree of freedom	Significant (2-tailed)
		Mean	Standard Deviation	Standard Error Mean	99% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Manual Reading - Vehicle Reading	-0.213	1.288	0.091	-0.449	0.024	-2.334	199	0.021

As mentioned earlier, for a 99% confidence interval the SPSS output window gives the p -value as 0.021 and α value is 0.01. The p -value is greater than 0.01 and this implies that the hypothesis has not been rejected. Therefore, there is no difference between the manual reading and vehicle reading at a 99% confidence interval.

Figure 5 represents the relationship of manual and vehicle readings for 35 km to 35.2 km chainages. According to that figure, there is a strong positive correlation between the manual reading and the vehicle reading. Hence both survey values are highly related.

Correlation values obtained for 95% and 99% confidence intervals are presented below.

For both confidence intervals, correlation values are obtained as 0.997. These correlation values are close to +1. Hence it can be predicted that data of both readings are highly related.

5. Conclusions

It was observed that manual and MFNSV inspection readings were almost the same. However, in some places differences between the two methods were noticed. Manual road inspection was carried-out after the MFNSV data collection. The time duration between the two inspections was around 5 months. It was assumed that there were no significant changes that have taken place in road failures during that time period. However, the gap in the duration in which the two surveys were done will slightly affect the difference in the two readings. For example, the cracks propagating along the road during that time are shown only in the manual inspection. In such places, manual reading takes a higher value than the MFNSV reading and in places where the failures were treated during that time belt the

Figure 5 - Graph of Manual and Vehicle Reading Data

Table 3 - Paired Sample Correlations for 95% and 99% confidence intervals

Sample Pair		Number of samples	Correlation
Pair 1	Manual Reading & Vehicle Reading	200	0.997

manual reading becomes lower than the MFNSV reading.

By conducting a sensitivity analysis it was found that the accuracy of the MFNSV inspection is quite high when compared with the manual road inspection. It was evident that, this vehicle can be recommended for inspection of long road stretches, since the manual method takes too much time and since it is labour intensive. Because of the high initial cost, conducting MFNSV inspection on short stretches is uneconomical. For such cases manual inspection is recommended.

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Appendix A

VISUAL ROAD CONDITION SURVEY FORM

Province: Western	District: Colombo
Road Number: A004	Division:
Road Name: A004	

Name of Surveyor(s):

Date: **04/05/2015**

Terrain Condition: Circle one
1 = Mountainous 2 = Rolling 3 = Flat

Pavement Type: Circle one
1 = Paved (Starbed) 2 = Unpaved (Gravel)
3 = Earth Road (Nil Gravel) 4 = Rigid

LEGEND

- Surface Type:**
(a) Asphalt Concrete (AC)
(b) Double Bituminous Surface Treatment (DBST)
(c) Single Bituminous Surface Treatment (SBST)
(d) Penetration Macadam (PM)
(e) Gravel (GR)
(f) Gravel Primed (GRP)
(g) Cement Concrete (CC)
(h) Block Paved (BL)

Shoulder Type:

- 1 = Paved (Block/Slab) 2 = Gravel Primed
3 = Unpaved (Gravel) 4 = Nil Shoulder

Brightness:

- 1 = Smooth 2 = Reasonably Smooth
3 = Medium Rough 4 = Rough
5 = Very Rough

Gravel Depth:

- 1 = 0 to 10mm
2 = 10 to 15mm
3 = >15mm

Road Side Info:

- 1 = Center Urban
2 = Outer Urban
3 = Rural

Drainage Type:

- 1 = Nil Drain
2 = Lined (Concrete or stone pitched) Drain
3 = Unlined Drain
4 = Not Required

Drainage Conditions:

- 1 = Free flowing / No blockages or scouring / erosion damage
2 = Blockage by siltation / debris / vegetation / Routine maint reqd
3 = Scouring / Erosion damage / Routine maint reqd
4 = Severe damage requires urgent rehabilitation or replacement

1000 m Speedometer Calibration
Kilometer reading (beginning):
Kilometer reading (end):
Kilometer reading error:

Survey Unit		Surface Type (a) - (h)	Road Width (m)	Shoulder Type (1-4)	Shoulder Width (m)	All roads		Unpaved		Paved				Drainage				Depot Name	DS Division	Road Side Info (1-3)	Comments
From (km)	To (km)					Roughness Value (1-5)	Severe Damage (m)	Rating / Corrugation (m)	Gravel Depth (1-3)	Surf. Defect	Cracking (m)	Edge Break (m)	Edge Drop (m)	Portions (No.)	Drainage Type (1-4)	Drainage Condition (1-4)	Drainage Type (1-4)	Drainage Condition (1-4)			
35.001	35.005	1	7.6	3	3.3					Skidding (m)	Longitudinal				1	-	3	1		2	
35.005	35.009	1	7.6	3	3.3					Skidding (m)	Longitudinal				1	-	3	1		2	
35.009	35.013	1	7.6	3	3.3					Skidding (m)	Longitudinal				1	-	3	1		2	
35.013	35.017	1	7.6	3	3.3					Skidding (m)	Longitudinal				1	-	3	1		2	
35.017	35.021	1	7.6	3	3.3					Skidding (m)	Longitudinal				1	-	3	1		2	
35.021	35.025	1	7.6	3	3.3					Skidding (m)	Longitudinal				1	-	3	1		2	
35.025	35.029	1	7.6	3	3.3					Skidding (m)	Longitudinal				1	-	3	1		2	
35.029	35.033	1	7.6	3	3.3					Skidding (m)	Longitudinal				1	-	3	1		2	

Appendix A - Figure A1 - Visual Inspection Survey Form

APPENDIX B

Table B1 – Visual and Manual inspection survey results

Visual inspection survey result from vehicle							Manual inspection survey results						
Chainage (km)	Lane Width (m)	Crack Area (m ²)	Defected Patch Area (m ²)	Raveling Area (m ²)	Pothole Area (m ²)	Total Percentage Failure %	Chainage (km)	Lane Width (m)	Crack Area (m ²)	Defected Patch Area (m ²)	Raveling Area (m ²)	Pothole Area (m ²)	Total Percentage Failure %
35.001	3.800	0.000	0.000	2.514	0.000	16.539	35.001	3.800	0.000	0.000	2.510	0.000	16.513
35.005	3.800	0.000	0.000	2.514	0.000	16.539	35.005	3.800	0.000	0.000	2.509	0.000	16.507
35.009	3.800	0.000	0.000	2.853	0.000	18.770	35.009	3.800	0.000	0.000	2.840	0.000	18.684
35.013	3.800	0.000	10.300	2.940	0.000	87.105	35.013	3.800	0.000	10.400	2.830	0.000	87.039
35.017	3.800	0.000	0.000	1.664	0.000	10.947	35.017	3.800	0.000	0.000	1.650	0.000	10.855
35.021	3.800	0.000	0.000	1.247	0.000	8.204	35.021	3.800	0.000	0.000	1.250	0.000	8.224
35.025	3.800	0.000	0.000	2.104	0.000	13.842	35.025	3.800	0.000	0.000	2.150	0.000	14.145
35.029	3.800	0.000	0.000	1.806	0.000	11.882	35.029	3.800	0.000	0.000	1.700	0.000	11.184
35.033	3.800	0.000	0.000	1.806	0.000	11.882	35.033	3.800	0.000	0.000	1.720	0.000	11.316
35.037	3.800	0.000	0.000	1.734	0.000	11.408	35.037	3.800	0.000	0.000	1.710	0.000	11.250
35.041	3.800	0.000	0.000	1.965	0.000	12.928	35.041	3.800	0.000	0.000	1.850	0.000	12.171
35.045	3.800	0.000	0.000	1.394	0.000	9.171	35.045	3.800	0.000	0.000	1.400	0.000	9.211
35.049	3.800	0.000	0.000	1.376	0.000	9.053	35.049	3.800	0.000	0.000	1.300	0.000	8.553
35.053	3.800	0.000	0.000	1.376	0.000	9.053	35.053	3.800	0.000	0.000	1.350	0.000	8.882
35.057	3.800	0.000	0.000	1.469	0.000	9.664	35.057	3.800	0.000	0.000	1.450	0.000	9.539
35.061	3.800	0.000	0.000	0.000	0.000	0.000	35.061	3.800	0.000	0.000	0.000	0.000	0.000
35.065	3.800	0.000	0.000	0.000	0.000	0.000	35.065	3.800	0.000	0.000	0.000	0.000	0.000
35.069	3.800	0.000	0.000	0.000	0.000	0.000	35.069	3.800	0.000	0.000	0.000	0.000	0.000
35.073	3.800	0.000	0.000	0.000	0.000	0.000	35.073	3.800	0.000	0.000	0.000	0.000	0.000
35.077	3.800	0.000	0.000	0.000	0.000	0.000	35.077	3.800	0.000	0.000	0.000	0.000	0.000
35.081	3.800	0.000	0.000	0.000	0.000	0.000	35.081	3.800	0.000	0.000	0.000	0.000	0.000
35.085	3.800	0.000	0.000	2.342	0.000	15.408	35.085	3.800	0.000	0.000	2.340	0.000	15.395
35.089	3.800	0.000	0.000	1.841	0.000	12.112	35.089	3.800	0.000	0.000	1.840	0.000	12.105
35.093	3.800	0.000	0.000	1.827	0.000	12.020	35.093	3.800	0.000	0.000	1.825	0.000	12.007
35.097	3.800	0.000	0.000	1.880	0.000	12.368	35.097	3.800	0.000	0.000	1.750	0.000	11.513
35.101	3.800	0.000	0.000	2.026	0.000	13.329	35.101	3.800	0.000	0.000	1.950	0.000	12.829
35.105	3.800	0.000	0.000	2.319	0.000	15.257	35.105	3.800	0.000	0.000	2.120	0.000	13.947
35.109	3.800	0.000	0.000	2.319	0.000	15.257	35.109	3.800	0.000	0.000	1.200	0.000	7.895
35.113	3.800	0.000	0.000	2.634	0.000	17.329	35.113	3.800	0.000	0.000	1.500	0.000	9.868
35.117	3.800	0.000	0.000	1.246	0.000	8.197	35.117	3.800	0.000	0.000	1.400	0.000	9.211
35.121	3.800	0.000	0.000	1.478	0.000	9.724	35.121	3.800	0.000	0.000	1.510	0.000	9.934
35.125	3.800	0.000	0.000	1.478	0.000	9.724	35.125	3.800	0.000	0.000	1.400	0.000	9.211
35.129	3.800	0.000	0.000	1.787	0.000	11.757	35.129	3.800	0.000	0.000	1.740	0.000	11.447