THE EFFECTIVENESS OF CONTROL OF SPEED BY ILLUSION LINES (COSBI LINES)

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ABSTRACT

The case study is on a section National Route (N2) near Somerset West/Strand, South Africa. The N2 is a divided dual carriageway surfaced freeway from Cape Town to the start of the experimental section located at the end of the freeway. The road changes from west to east from a high-speed zone to a low-speed zone, leading into two left and a right curves with a priority controlled intersection between the left and right curves. The change from a high- to a low-speed zone results from a change in road classification from a freeway posted at 120 km/h to urban arterial posted at 60 km/h. The geometry approaching the curves from the west is a 2 km straight section of freeway. The geometry allows the motorist to travel at speed around the curve but it is a safety risk due to the reverse curves and the intersection between the curve, as well as queuing in the afternoon peak periods due to the set of traffic signals 1,44 km to the east.

Control of Speed by Illusion (COSBI) lines are 600 mm wide transverse painted markings (bars) that are set out at a gradually decreasing spacing that gives the motorist the illusion that he is increasing his speed. This is known as a set of bars. The spacing of the COSBI lines was calculated to reduce the speed of the motorist from 120 km/h to about 60 km/h. It would be normally recommended that the road marking material be thermo-plastic or cold melt plastic to ensure that there is a slight level difference. With the level difference, the bars also act as a rumble strip. For this case study the use of normal retro-reflective road marking paint was used as the road is to be resurfaced.

The South African National Road Agency SOC Limited (SANRAL) approved, the case study to determine the effectiveness of COSBI lines by performing a speed study before and after the application thereof. Speeds were measured by means of a radar gun. The disadvantage of using a manual speed measuring device is that the speeds of only isolated vehicles or the first vehicle in a platoon can be measured. This was not considered a severe constraint as both the before and after studies were done under the same constraint and the single or leading vehicle would be the speeding vehicle of which the behaviour needs to be monitored and changed.

The case study found that a 10 to 15 km/h speed reduction was achieved with before speeds of up to 87 km/h reducing to 72 km/h over the short term as measurements were made about the day after and 5 weeks after installation. It is recommended that longer term after studies be done to check if drivers revert to previous speeds. The design procedures formulated by Katz (2007) is not applicable to local conditions.

1. INTRODUCTION

This case study investigated the effectiveness of Control Of Speed By Illusion (COSBI) lines in the reduction of speed from a high-speed zone to a low-speed zone as an additional safety measure at the end of the freeway. A literature study was on the design of and previous studies on COSBI lines.

The investigation was restricted to a specific case study on one road to investigate the effectiveness of COSBI lines in speed reduction under South African conditions. The motorist's speed was measured by means of a Bushnell Velocity Radar Gun. Single reading was taken and recorded manually. The accuracy of the radar gun is ± 2 km/h and speed can be measured up to a distance of 450 meters. The disadvantage of using a manual speed measuring device is that only the speeds of isolated vehicles or the first vehicle in a platoon can be measured. This was not considered a severe constraint as both the before and after studies were done under the same constraint and the single or leading vehicle would be the speeding vehicle of which the behaviour needs to be monitored and changed. The case compares average speed per vehicle group before and after to show how effective COSBI lines are in the reduction of speed from a high-speed zone to a low speed zone.

2. LITERATURE STUDY

The control of a driver's speed by means of signage without enforcement is not effective. Alternative methods could make use of a wider range of the driver's senses. Control of Speed by Illusion (COSBI) was devised by applying road markings and/or textured surfaces to create an illusion to the drivers that they are speeding by triggering the visual and hearing senses. The use of these types of speed reduction measures have advantages. The biggest advantage is that motorist subjectively reduce their speed. The implementation of these measures is cost effective and easily installed Rothernberg (2007). Applying COSBI lines on a roadway could reduce the speed by at least 10% according to Havell (1983).

COSBI lines are 600 mm wide transverse white road marking bars across the width of the roadway. If painted with a thick medium such as thermo plastic, they also act like rumble strips. The white road marking colour is used in South Africa as the yellow road markings are reserved for left edge lines, parking prohibitions, mandatory arrows and painted island bars according to Havell (1983). The marking is set up in such a way that it creates the illusion, to the drivers, that they are speeding up as they cross the lines. The illusion is achieved by having multiple sets of bars at reducing spacing. When multiple sets of bars are used they are placed in a sequence of primary and secondary sets of bars. The primary set of bars has the same spacing, while the secondary set the spacing decrease as calculated according to Katz (2004).

According to Katz (2007) the formula for calculating the spacing is based on the time intervals Δt can be related to the number of bars (n) and the bar frequency (f) in bars per second using the formula:: Δt = (n/f), leading to the formula:

$$x_t = \frac{1}{2} a \left(\frac{n}{f}\right)^2 + v_0 \left(\frac{n}{f}\right) + x_0 \qquad (1)$$

x_t = displacement from end treatment (m) to each individual bar (t)
a = acceleration (m/s^2)

n = number of bars
f = bar frequency
v_0 = initial speed entering the treatment (m/s)
x_0 = distance from the beginning of the treatment area (m)

A comparison was drawn between this formula and the standard displacement formula. Table 2 shows the comparison of the two formulas. For this case study, the standard displacement formula was used to determine the spacing of the bars.

3. CASE STUDY

3.1 Location and background

The case study is located in the Western Cape Province, South Africa within the City of Cape Town Metropolitan Municipality. It is on National Route 2, section 1, which is under the jurisdiction of the South Africa National Road Agency Soc Ltd from east of Baden Powell Interchange (km 29,00) to east of Broadway Boulevard Interchange (km 40,20). The National Route 2 is a major highway and a popular tourist route that links cities and towns such as Cape Town, Mosselbay, George to Port Elizabeth and Durban, continuing up to Richardsbay near the Mozambique border and to Ermelo in Mpumalanga.

In a recent rehabilitation assessment of the National Route 2, section 1, it was found that drivers travel at high speeds (freeway speed limit being 120 km/h) into the low speed zone at the end of the freeway. The low speed zone is the result of unforgiving geometry with broken back left-hand curves followed by a right-hand (reverse) curve with a priority controlled intersection between the second left- and right-hand curves. The roads classification changes from a high-speed freeway, sign posted at 120 km/h to a low speed urban arterial, sign posted at 60 km/h. The geometry allows the motorist to travel at speed around the left-hand curves under favorable weather and traffic conditions, but it is a safety risk due to the relatively sharp curves and the priority controlled intersection within the curves. The speed limit before you reach the first bend is set to 70 km/h. The road geometry is safe at the first bend with a radius of 250 m to travel at 90 km/h while the second bend with a radius of 200 m is safe to travel at 70 km/h if the superelevation is at a 6% with a emax of 6%. This creates a sense of safety for a driver to travel faster than the speed limit of 70 km/h through the first bend.

The consulting engineer that assessed the road section, in collaboration with the client, investigated the possibility of safety measures that can be implemented to reduce speeding on the approach and around the curves.

3.2 Speed study before

A speed study was performed prior to the installation of COSBI lines marking. The measurements were taken at three different location namely the LHS (Left Hand Side) Culvert, Median and Site Camp. These three locations were chosen to see the drivers speed before the COSBI lines, over the COSBI lines and after the drivers has passed the COSBI lines. These three locations were spread over a distance of 150m from the LHS Culvert to the site camp. The position of the COSBI lines were to be placed before the driver enters the first left-hand curve to slow the speed down before the relatively sharp right-hand curve. Figure 1 shows the location of the three measuring points that were used. These three positions were chosen so that the radar gun would not be too conspicuous to the drivers allowing them to behave normally. The recordings were done on Thursday 29

November 2018. The road was in a good condition and the weather was sunny to partly cloudy. The construction activities associated with the rehabilitation of the road section (milling and resurfacing) were far away enough to not influence the speeds.

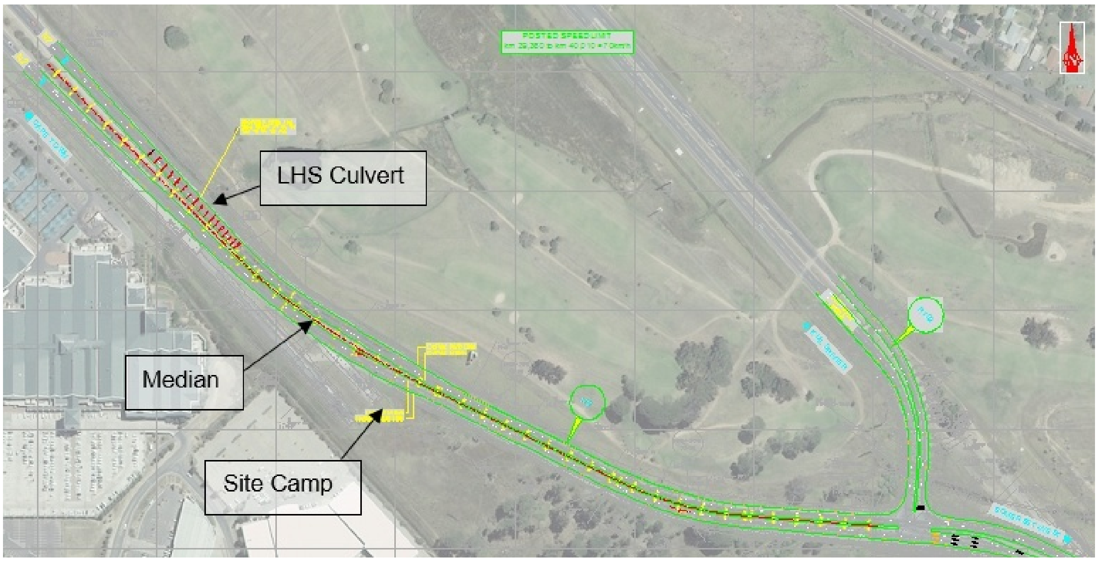

Figure 1: Location of the three measuring stations

At the LHS Culvert, the radar gun was set up at an approximate height of 500 mm. With the radar gun set up at a low height and next to a hazard plate was being partially hidden from for the driver. Figure 2 shows the position of the radar gun at the LHS Culvert location set up next to a hazard plate. At this position, a 5% correction factor had to be factored in because the radar gun was not set up in a direct line of sight with the vehicles being measured. The readings were taken at a slight angle. This is called the Cosine Effect. A total of 338 vehicle's speeds were recorded over a period of 1-hour (09:00 am to 10:00 am). Table 1 shows the average speeds that was recorded at this location. The reading was taken when the vehicles were between 50 and 80 m from the measuring points.

Figure 2: Radar Gun set up at LHS Culvert

At the median, the radar gun was set up at an approximate height of 800 mm. With the radar gun set up at this height it was just above the guardrail. This would make it less visible to the motorist as the approach the radar gun. Figure 3 shows the setup of the radar gun behind the guardrail in the Median. At this position the reading was accurate as the radar gun was in the direct line of travel. A total of 529 vehicle speeds were recorded over a period 10:37 am to 12:00 pm). Table 1 below shows the average speeds that was recorded at this location. The reading was taken when the vehicles were between 50 and 80 m from the measuring points.

Figure 3: Radar Gun set up behind Guardrail in the Median

At the site camp, the radar gun was set up at an approximate height of 1100 mm. With the radar gun set up at this height it could sight the vehicle over two lanes of opposing traffic and the median island. Figure 4 shows the setup at the site camp and the line of sight over the two opposing lanes and median island. At this position the reading was accurate as the radar gun was in the direct line of travel, however the reading was more difficult to take due to the distance to the oncoming traffic.

The speed measurements at this location were taken when there was a gap in the west-bound traffic and a clear line of sight towards the oncoming eats-bound traffic. A total of 528 vehicle speeds were recorded over a period 13:35 pm to 15:30 pm. Table 1 below shows the average speeds that was recorded for this section. Observations were taken at the site camp and where vehicles being measured has just gone over the COSBI lines.

Figure 4: Radar Gun set up at Site camp

The speeds were recorded at all three the location. Table 1 shows the average speed achieved by the motorist before entering the first curve. These speed measurements were done before the COSBI lines were applied.

Table 1: Average Speed before COSBI Lines application

Average Speed (km/h)			
Type of Vehicle	LHS Culvert	Median	Site Camp
Cars	89.98	87.47	83.76
SUV (Sport Utility Vehicle)	89.45	88.67	82.97
LDV (Light Duty Vehicle)	89.22	88.44	84.35
Trucks	79.91	77.77	74.75
Other	87,00	88.36	83.14
Overall average speed	**87.11**	**85.59**	**81.46**

Each of the locations had its own difficulty regarding the taken of the readings. These were mentioned in the varies sections above.

3.3 Control of Speed by Optical Illusion Lines Calculations

The COSBI lines spacing would be calculated to reduce the speed by about 50% from 120 km/h to 60 km/h. The assumptions for reducing speed from a initial to a target speed are that the deceleration rate can be prescribed (a range of 1 to 3 m/s² reported in Katz 2007) and the frequency of bars that are effective is known (a range of 2 or 4 per second (Katz 2007). No justification for the spacing based on research of driver perception is given, only that in the research by Katz, Duke and Rakha (2006) and Katz, Molino and Rakha (NA) (quoted in Katz (2007) that came to the conclusion that 4 bars per second (4 Hz) were more effective that 2 bars per second 2 Hz).

The spacing of the transverse bars can be calculated by means of either of the following two formulas:

Formula 1 (Katz, 2007):

$$x_t = \frac{1}{2}a\left(\frac{n}{f}\right)^2 + v_0\left(\frac{n}{f}\right) + x_0 \tag{2}$$

x_t = displacement from end treatment (m) to each individual bar (cumulative)
a = acceleration (m/s^2) (assumed value)
n = number of bars
f = bar frequency (4 per second found effective)
v_0 = initial speed entering the treatment (m/s)
x_0 = distance from the beginning of the treatment area (m)

Formula 2:

$$s = \frac{v^2 - u^2}{2a} \tag{3}$$

s = displacement (m) (treatment length if using design initial and final values)
v = final velocity (m/s)
u = initial velocity (m/s)
a = acceleration (m/s²)

Katz use a range of 1 to 3 m/s^2 as viable, noting that 2 m/s^2 is considered comfortable. 3.5 m/s/s is used in stopping sight distance calculations. The 5 m/s/s used in the case study may be considered excessive as the driver must apply brakes instead of just letting out the fuel pedal.

Table 2 shows the bar spacing for the case study. To reduce speed from 120 km/h (33.33 m/s) to 60 km/h (16.67 m/s) with the chosen deceleration rate of 5.0 m/s requires a distance of $(33.33^2-16.67^2)/(2*5) = 81.3$ m

The time to reduce speed from 33.33 m/s to 16.66 m/s v1 – v0 = at
Thus at =16.66 = 5t
And t = 16.66/5 = 3.33 sec.

At 4 bars per second 4 * 3.33 = 13.33 say 14 bars

The time at the speed per bar interval is 3.33 sec / 13 = 0.2538 sec, which is slightly longer than the 4 Hz frequency of 0.25 seconds due to the rounding up of the number of bars. This is not significant.

At constant deceleration the speed (rounded) reduces nearly linearly from 33 m/s to 17 m/s in 13 steps. By calculating the distance per time interval from the speed x 0.25, the spacing of the bars are obtained and can be accumulated to the length of the COSBI zone.

Table 2: COSBI Lines Spacing

Starting Speed u:	**120**	km/h	*74.6 mph*	**33.3**	m/s
End Speed v:	**60**	km/h	*37.3 mph*	**16.7**	m/s
Total Distance:	**81.5**	m	*267.4 feet*		
f:	**4**	bars/s	a:	**-5.1**	m/s2

Bar (n)	**Speed (m/s)**	**Speed (km/h)**	**Spacing (m) (Formula 2)**		**Spacing (m) (Formula1)**
			Bar to Bar	**Cumulative**	**Cumulative (xt)**
1	33	120.0			8.174
2	32	115.4	8.174	8.174	16.028
3	31	110.8	7.854	16.028	23.562
4	29	106.2	7.535	23.562	30.777
5	28	101.6	7.215	30.777	37.673
6	27	97.0	6.895	37.673	44.248
7	26	92.4	6.576	44.248	50.505
8	24	87.8	6.256	50.505	56.442
9	23	83.2	5.937	56.442	62.059
10	22	78.6	5.617	62.059	67.357
11	21	74.0	5.298	67.357	72.335
12	19	69.4	4.978	72.335	76.994
13	18	64.8	4.659	76.994	81.333
14	17	60.2	4.339	81.333	85.353

From the table above there is a difference between the two formula's cumulative distances at bar number 14. Due to the result of the total length of the COSBI lines, the spacing between the bars would also differ. For this case study, the bar spacing obtained from Formula (2) was used to set out the bars on the road.

The COSBI lines were painted on 12 December 2018. Retro-reflective road marking paint was used for this case study. The 14 bars would be applied as the secondary set of bars with the spacing calculated in Table 2. A primary set of three bars was painted using the same bar spacing as the first bar, for a total of 17 bars. Figure 5 shows the COSBI lines as painted.

Figure 5: COSBI Lines applied

<u>3.4 Speed study after</u>

The after speed studies were performed after the installation of COSBI lines marking. The measurements were taken at the same positions, day of the week (Thursday) and time of day as the before study. The measurements were taken on 13 December 2018 (928 vehicles were observed) and 10 January 2019 (1374 vehicles were observed). Measurement on the day after the painting of the lines and the start of the school holiday should be treated with circumspection. New signs and markings have a novelty effect and drivers' reactions have not stabilised. The measurements that were taken on 13 December 2018, were only taken at two locations. The two locations were the LHS Culvert and the Median. The reason for this was the start of the school holidays and the vehicles were backing up to a point that traffic started slowing down over the COSBI line markings and measurements at the site camp location was not possible. The measurements taken on 10 January 2019 were taken at all three locations. The road was in a good condition and the weather was partly cloudy.

The radar gun setup at these locations was done in the same way as the before study.

Table 3 shows the average speed achieved by the motorist before entering the curves after the COSBI lines were applied at the three locations.

Table 3: Average speed after COSBI Lines application

<table>
<tr><th colspan="7">Average Speed (km/h)</th></tr>
<tr><th>Type of Vehicle</th><th colspan="2">LHS Culvert</th><th colspan="2">Median</th><th colspan="2">Site Camp</th></tr>
<tr><td></td><td>13/12/2018</td><td>10/1/2019</td><td>13/12/2018</td><td>10/1/2019</td><td>13/12/2018</td><td>10/1/2019</td></tr>
<tr><td>Cars</td><td>75.12</td><td>73.22</td><td>74.92</td><td>73.34</td><td rowspan="6">DID NOT DO MEASURMENTS DUE TO THE TRAFFIC BACKED UP OVER COSBI LINES</td><td>72.04</td></tr>
<tr><td>SUV</td><td>76.89</td><td>74.40</td><td>75.46</td><td>75.47</td><td>73.14</td></tr>
<tr><td>LDV</td><td>73.19</td><td>74.16</td><td>75.18</td><td>74.14</td><td>72.74</td></tr>
<tr><td>Trucks</td><td>64.57</td><td>65.31</td><td>65.73</td><td>67.22</td><td>65.93</td></tr>
<tr><td>Other</td><td>75.84</td><td>72.74</td><td>76.52</td><td>79.63</td><td>71.93</td></tr>
<tr><td>Overall average speed</td><td>72.44</td><td>71.97</td><td>72.82</td><td>72.54</td><td>70.96</td></tr>
</table>

3.5 Speed comparison

The before and after readings were done on the same day of the week, at the same time, same three locations and approximately the same number of cars. Figure 6 shows the comparison of average speeds that the vehicles were traveling before and after the COSBI lines was applied.

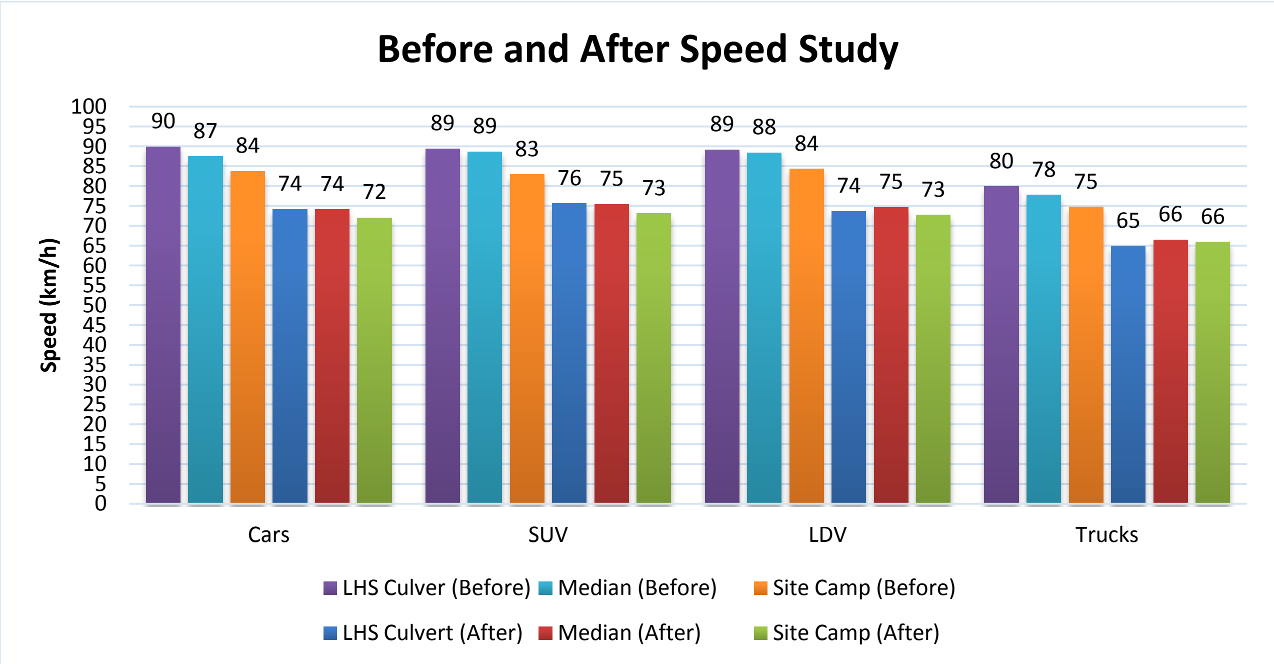

Figure 6: Speed Comparison graphs of before and after study

From the data depicted in the graph there is a clear indication of a reduction in average speed. The before readings are higher than the after readings. The average speed before the marking were applied was between 81,5 km/h and 87,2 km/h at the three locations. After the COSBI lines were painted the average speed decreased to between 71,9 km/h and 70,9 km/h. This shows a decrease in average speed of 15%. Although according to Havel (1983) the reduction in speed may be as low as 10%.

The design of the set of COSBI lines were based on the assumption of a deceleration rate of 5 m/s/s that would reduce speed from 120 to 60 km/h. The initial speed, based on the speed limit, was estimated much too high as the before study showed the initial speed measured at the culvert as 87 km/h. The design was supposed to reduce the speed by 50%, while the actual effect was measured to be 15%. The design approach developed mainly by Katz (2007) can therefore not be used in South Africa. The experimental setup and the manner of taking speed measurement with a radar gun, which cannot pinpoint the location of the vehicle when the reading is taken, made it impossible to measure the change in speed while driving over the set of COSBI lines. At best it can be observed that the reduction in speed occurred before the COSBI lines and not so much while driving over them. The COSBI lines seems to act as effective warning markings due to its visibility over a long distance in low flow conditions. The study did not extend sufficiently long to evaluate the recovery effect over time.

4. CONCLUSIONS

The National Route 2, section 1 case study analysed measurements that were taken before and after the installation of COSBI lines. The following conclusions can be made.

The use of COSBI lines in the form of 14 bars over a distance of 81 m at the end of a freeway shows a reduction in average speed between 10 and 15% immediately and in the month after implementation. This is an indication that COSBI lines can be effective on a road section where hazardous conditions exist, and drivers react to the improved warning. Care was taken in performing the study in such a way to reduce the influence on the motorists to behave abnormally. There is a need to extent the time period over which driver behaviour must be monitored to determine the recovery effect. Design procedures developed in the USA cannot be transferred to local conditions. Further research needs to be done under local conditions.

5. RECOMMENDATIONS

The following recommendations are made on the findings of the application of COSBI lines in this case study:

- For this case study, retro-reflective road marking paint was use however it is recommended that the Thermo-plastic or Cold melt plastic type road marking paint be used. This is to create the rumble strip effect as these markings are a couple of mm higher than the road surface. This would be a good practice where these markings are used in urban areas.
- When these markings are used in rural areas is could be used in conjunction with rumble strips. The rumble strips would then be placed at the same spacing as the COSBI lines and would be painted to create a 3-dimensional look to the COSBI line markings.
- Further research needs to be done under local conditions.
- Additional speed tests should be perform up to two years after road markings application.

6. ACKNOWLEDGEMENT

We would like to take this opportunity to acknowledge Mr Renaldo Lorio from SANRAL for allowing us to perform the COSBI lines case study on National Route 2, Section 1 as part of an existing road rehabilitation project.

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