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ESTIMATION OF ROAD ROUGHNESS INDEX FROM PAVEMENT TO CALCULATE VEHICLE OPERATING COST

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Abstract— The roughness of a road's surface is an important measure of road condition and a key factor in determining vehicle operating costs. It is an important pavement characteristic because it affects not only ride quality but also vehicle delay costs, fuel consumption and maintenance costs. So here we are finding Vehicle operating cost (VOC), which is a major part of road user costs through finding road roughness of few most used road-stretches in Amrita University, Coimbatore. This study is based on an effort to find out how a road characteristic affects the road users to spend money on their vehicles. Our objective is to find road roughness index and incorporate it in a VOC Model to find vehicle operating costs (road user costs). We have adopted Dumpy Level to International Roughness Index which is like MERLIN's methodology. VOC is an integral part of the economic benefit estimation in the economic evaluation in feasibility studies of highway project. The operating cost of a vehicle type is a function of several variables including road condition, travel speed, road geometry and many other parameters. VOC is the cost that is required to run a vehicle in each section of a pavement which includes fuel and oil consumption, tire wear, vehicle maintenance and depreciation. Road roughness, which is measured in terms of IRI, has a significant impact on VOC. The tool for estimating life-cycle costs on roads is based on the Highway Design and Maintenance Standards Model (HDM-III) Developed by the World Bank. VOC values were estimated by using the HDM-III model. According to IRI values, all three road stretches are in good condition. The road stretches that have higher IRI values have higher Vehicle Operating Costs and vice-versa. This approach can be useful for the calculation of IRI and VOC on a small-scale level swiftly.

Index Terms— Transportation Engineering, Road Roughness Index, Level Surveying, Modelling, Vehicle Operating Costs.

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1 INTRODUCTION

The longitudinal unevenness of a road's surface (normally termed as roughness) is both a good measure of the road's condition and an important determinant of vehicle operating costs and ride quality. Within developing countries, there is particular interest in the effect on vehicle operating costs [1]. Several studies have shown how roughness can influence the cost of vehicle maintenance, the rate of tire wear, and vehicle running speeds (and hence vehicle productivity).

Reliable measurement of road roughness is therefore seen as an important activity in road network management. A variety of machines have been developed to make these measurements, and several roughness scales have been established

Road roughness index measures deviations from the intended longitudinal profile of a road surface, with characteristic dimensions that affect vehicle dynamics, ride quality and dynamic pavement loading [1]. The IRI[1] is a profile-based roughness statistic that has become a standard indicator of road roughness. The main objective of that research program was to develop a time stable means for calibrating response-type systems. A mathematical transform of the measured longitudinal profile was proposed as a calibration reference. The analysis method was further developed, simplified, and standardized under funding from The World Bank. The index obtained with the standardized method was called IRI, and guidelines were prepared for measuring it with a variety of equipment, including profilers.

Even if a road is constructed with high-quality pavers, it is possible to develop unevenness due to pavement failures. Unevenness index is a measure of unevenness which is the cumulative measure of vertical undulations of the pavement surface recorded per unit horizontal length of the road [1].
Higher operating speeds are possible on even pavement surfaces with fewer undulations than on uneven and poor surfaces. It has been shown from tests that it is desirable to keep the unevenness index low, and preferably less than 1500 mm/km for good pavement surfaces of high-speed highways.
2500mm/km – 100 kmph
3500mm/km – 50 kmph [3]

Abbreviations :
[2]IRI – International Roughness Index

Vehicle operating costs refer to costs that vary with vehicle usage, including fuel, tires, maintenance, repairs, and mileage-dependent depreciation costs. Projects that alter vehicle km's travelled, traffic speed and delay, roadway surfaces, or roadway geometry may affect travelers' vehicle operating costs, which should be considered in a benefit-cost analysis. *Vehicle ownership costs* refer to fixed costs that are not directly affected by vehicle mileage, including time-dependent depreciation, insurance and registration fees, financing, and residential parking. Projects that change per capita vehicle ownership rates, such as significant changes in the quality of alternative modes and land use accessibility, may affect vehicle ownership costs, which should be considered in benefit-cost analysis [4].

1.2 Objectives:

- To estimate road roughness index.
- To calculate vehicle operating cost

1.3 Estimation of IRI[2]:

There are many ways to find the road roughness index. So, we have gone through and referred few papers and methods to determine IRI. Here are few ways:

1.3.1 Different Methods to Measure IRI:

Manual Mapping:

The manual mapping method used for field testing consisted of a rater walking pavement section and manually drawing a map showing the type section and manually drawing a map showing the type and exact location of all distresses present on the section.

Detailed Visual Survey:

a) **Manual Recording:** The PAVER[3] and concrete pavement evaluation system (COPES[4]) methods of conducting condition surveys were selected as representative detailed visual distress survey methods. PAVER is a pavement evaluation system. The detailed condition survey procedure employed by the PAVER system was used for the flexible, composite, and jointed reinforced concrete pavement sections in the field study.

b) **Automatic Data Logging:** The detailed distress survey using a field data logger was performed using a battery-operated portable computer to record distress and section information. The interactive program prompts the rater for the input of the severity and extent of each previously defined distress category. The information is stored on a computer encoded microcassette.

c) **PASCO ROADRECON:** PASCO corporation of japan developed the continuous pavement surface photographing device (ROADRECON-70). Cracking, patching, and other distresses are recorded using the ROADRECON-70 [5]. The vehicle travels at speeds between 3 and 53mph. a continuous photographic record of the pavement surface is made using a 35mm slit camera.

d) **GERPHO:** The groupe examen routier photographic (GERPHO) system, employs a survey vehicle to take continuous 35mm photographs of the pavement surface. The GERPHO[5] system consists of a 35 mm continuously running (strip film) camera, mounted on a van, with a light source that illuminates the pavement. The pavement surveys are conducted at night to allow for uniform lighting conditions.

e) **Automatic Road Analyzer (ARAN):** The ARAN[6] measures rut depth and transverse profile with ultrasonic sensors and ride/roughness quality with an accelerometer on the rear axle. The ARAN also takes a video picture of the road right-of-way through the windshield and the pavement surface with a shuttered video camera.

f) **Laser Road Surface Tester (RST):** The laser RST[7] can reportedly measure crack depths and widths, rut

[2] IRI – International Roughness Index
[3] PAVER - Pavement Evaluation System
[4] COPES - Concrete Pavement Evaluation System
[5] GERPHO: The Groupe Examen Routier Photographic System.
[6] ARAN: Automatic Road Analyzer.
[7] RST: Laser Road Surface Tester.

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depths, longitudinal profile from which roughness is computed, macrotexture, cross profile, and distance [5].

g) **MERLIN[8]:** The device can be used either for direct measurement or for calibrating response-type instruments such as the vehicle-mounted bump integrator. It consists of a metal frame 1.8 m long with a wheel at the front, afoot at the rear [1].

1.3.2 Different models to find VOC: (which can be considered)

1. The World Bank's HDM-3 and HDM-4 VOC models (Bennett and Greenwood, 2003).
2. Texas Research and Development Foundation (TRDF) VOC model. (Zaniewski et al., 1982).
3. MicroBENCOST VOC model (McFarland et al., 1993).
4. Saskatchewan VOC models (Berthelot et al., 1996).
5. British COBA VOC module (British Department of Transportation, 1993).
6. Swedish VETO model (Hammerstrom and Karlsson, 1991).
7. Australian NIMPAC VOC module (National Association of Australian State Road Authorities, 1978).

2 METHODOLOGY

- **Steps to find IRI:**
    - Data collection. (Finding Levels by surveying).
    - Finding IRI[9] manually using MERLIN[10]'s methodology.
    - Incorporating IRI values in the VOC[11] model to find vehicle operating costs.
    - Analysing the values.

Not long after the construction of a pavement or a new pavement surface, various forms of deterioration begin to accumulate because of the harsh effects of traffic loading combined with weathering action [6]. Many indices represent pavement conditions. The international roughness index (IRI) is widely used to quantify pavement smoothness. From the viewpoint of driving comfort, smoothness is considered the most important aspect of pavement condition, and it is especially important for pavements with elevated speed limits.

Data used for finding out International Roughness Index (IRI) was obtained by conducting surveys at Amrita University. The reduced level of each point was measured by using dumpy level and levelling staff (using Leveling: Rise and Fall Method).

There are many models to estimate Vehicle Operating Costs. HDM-III[12] model works best for our requirements. HDM-III model gives a direct relationship between IRI and VOC for different types of vehicle models.

3 DATA COLLECTION

3.1 GENERAL

To evaluate the vehicle operating cost a survey is conducted to determine International Roughness Index Data used for finding out International Roughness Index (IRI) was obtained by conducting a survey in Amrita University. The reduced level of each point was measured by using dumpy level and levelling staff (using Leveling: Rise and Fall Method).
Using a dumpy level and levelling staff, a reduced level of points spaced at 1.8m from each other is measured.
Merlin -machine for evaluating roughness using low-cost in-

[8] MERLIN - Machine for Evaluating Roughness using Low-cost Instrumentation.

[9] IRI – International Roughness Index.

[10] MERLIN - Machine for Evaluating Roughness using Low-cost Instrumentation.

[11] VOC – Vehicle Operating Cost.

[12] HDM-III - Highway Design and Maintenance Standards Model.

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strumentation. The device can be used either for direct measurement or for calibrating other instruments such as vehicle-mounted Bump Integrator. It only measures 200 observations (maximum) at a stretch

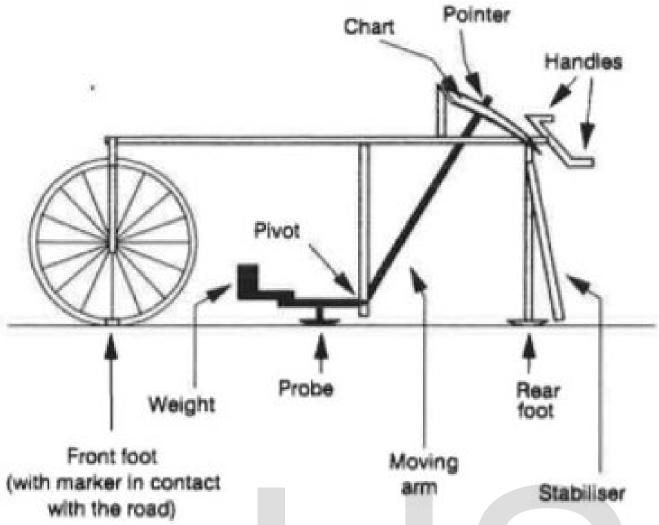

FIGURE 3.1 MERLIN- A LOW-COST MACHINE FOR MEASURING ROAD ROUGHNESS IN DEVELOPING COUNTRIES WITH A WHEEL AND PROBE TO NOTE DOWN EVENNESS.

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3.2 SITE SELECTION:

We have surveyed a total of 3 stretches in Amrita University, Coimbatore:

1. From MBA Block to Library.
2. From MBA Block to AB-1.
3. From Main Gate to Saraswathi Statue Road.

These are the major roads used on campus. For each stretch, we have surveyed the left and right segments of the road.

Figure 3.2 Dumpy level

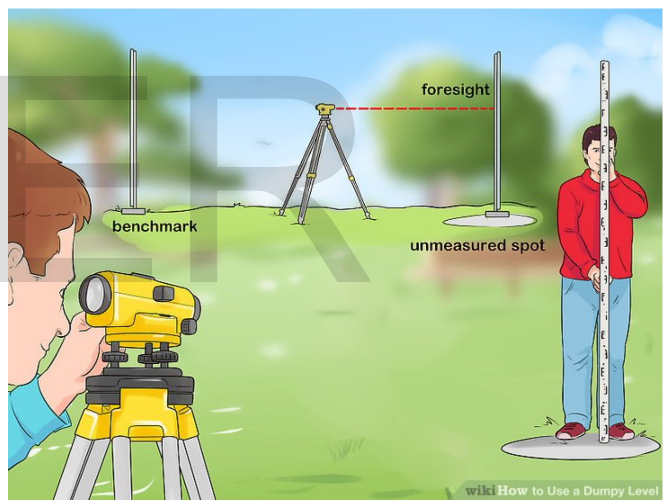

Figure 3.3 Surveying (using a dumpy level)

3.3 DATA COLLECTION:

Figure 4.1 shows a sketch of the device. For use of operation a wheel is used as the front leg, the rear leg is a rigid metal rod. The diameter of the wheel is approximately 250-300mm. Hence the circumference is approximately 1.5-2m. To measure the roughness over a stretch of road, 200 observations are made at regular intervals. At each observation, the machine is rested on the road with the wheel in its normal position and the rear foot, probe, and stabilizer in contact with the road surface.

The position of the pointer on the chart is then recorded with a cross in the appropriate column and, to keep a record of the total number of observations [1] made, a cross is also recorded in the tally box on the chart.

The handles of the MERLIN[13] are then raised so that only the wheel remains in contact with the road, and it is moved forward to the next sample position, where the process is repeated. The spacing between the sample positions is not critical but readings must always be taken with the wheel in the normal position and so the spacing of one-wheel circumference is the most convenient in practice.

Similarly, we have incorporated this in our methodology using dumpy level and levelling staff to find the road roughness index. In Merlin, the probe takes readings of the undulations after one revolution and records them in a graph. Here, we are using the dumpy level and the levelling staff and taking the readings of points spaced at 1.8m (circumference of MERLIN wheel) from each other. The R.L of each point will be calculated (rise and fall method-figure 3.2). The longitudinal cross-section of the road can be drawn in the AUTOCAD from the obtained R.L's.

LEFT

SI NO.	STATION	BACK SIGHT	INTER SIGHT	FORE SIGHT	RISE	FALL	R.L	REMARKS
		1.475					1000	BENCH MARK
1	1	1.395			0.08		1000.08	
2			1.395		0		1000.08	
3			1.445			0.05	1000.03	
4			1.425		0.02		1000.05	
5			1.415		0.01		1000.06	
6			1.44			0.025	1000.035	
7			1.465			0.025	1000.01	
8			1.45		0.015		1000.025	
9			1.445		0.005		1000.03	
10			1.435		0.01		1000.04	
11			1.43		0.005		1000.045	
12			1.415		0.015		1000.06	
13			1.405		0.01		1000.07	
14			1.41			0.005	1000.065	
15			1.395		0.015		1000.08	
16			1.375		0.02		1000.1	
17			1.34		0.035		1000.135	
18			1.3		0.04		1000.175	
19			1.275		0.025		1000.2	
20			1.175		0.1		1000.3	
21			1.235			0.06	1000.24	
22			1.21		0.025		1000.265	
23			1.17		0.04		1000.305	
24			1.14		0.03		1000.335	
25			1.11		0.03		1000.365	
26			1.09		0.02		1000.385	
27			1.08		0.01		1000.395	
28			1.06		0.02		1000.415	
29			1.06		0.01		1000.425	
30	2	1.775		1.05			1000.425	CHANGE PO[illegible]

Sheet1

Figure 3.4 Reduced Levels of a Stretch (left)

RIGHT

SI NO.	STATION	BACK SIGHT	INTER SIGHT	FORE SIGHT	RISE	FALL	R.L	REMARKS
		1.475					1000	BENCH MARK
1	1	1.36			0.115		1000.115	
2			1.365			0.005	1000.11	
3			1.35		0.015		1000.125	
4			1.355			0.005	1000.12	
5			1.355		0		1000.12	
6			1.36			0.005	1000.115	
7			1.365			0.005	1000.11	
8			1.375			0.01	1000.1	
9			1.365		0.01		1000.11	
10			1.345		0.02		1000.13	
11			1.33		0.015		1000.145	
12			1.305		0.025		1000.17	
13			1.28		0.025		1000.195	
14			1.255		0.025		1000.22	
15			1.245		0.01		1000.23	
16			1.235		0.01		1000.24	
17			1.225		0.01		1000.25	
18			1.22		0.005		1000.255	
19			1.205		0.015		1000.27	
20			1.145		0.06		1000.33	
21			1.175			0.03	1000.3	
22			1.16		0.015		1000.315	
23			1.13		0.03		1000.345	
24			1.1		0.03		1000.375	
25			1.075		0.025		1000.4	
26			1.07		0.005		1000.405	
27			1.05		0.02		1000.425	
28			1.015		0.035		1000.46	
29	2	1.72		1.095			1000.46	CHANGE POINT
30			1.645			1.645	998.815	
31			1.64		0.005		998.82	
32			1.64		0		998.82	
33			1.63		0.01		998.83	

Sheet1

Figure 3.5 Reduced Levels of a Stretch (right)

4 DATA ANALYSIS (FINDING IRI)

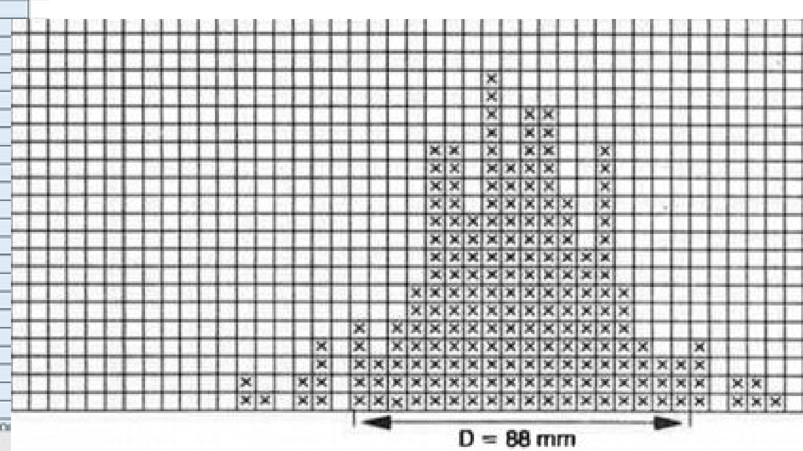

Figure 4.1 An Ideal Histogram that was already plotted to find D (sample).

13 MERLIN - Machine for Evaluating Roughness using Low-cost Instrumentation

Figure 4.1 is a sample histogram to find D.

D is the spacing between 2 marks in the graph (measured in mm.)

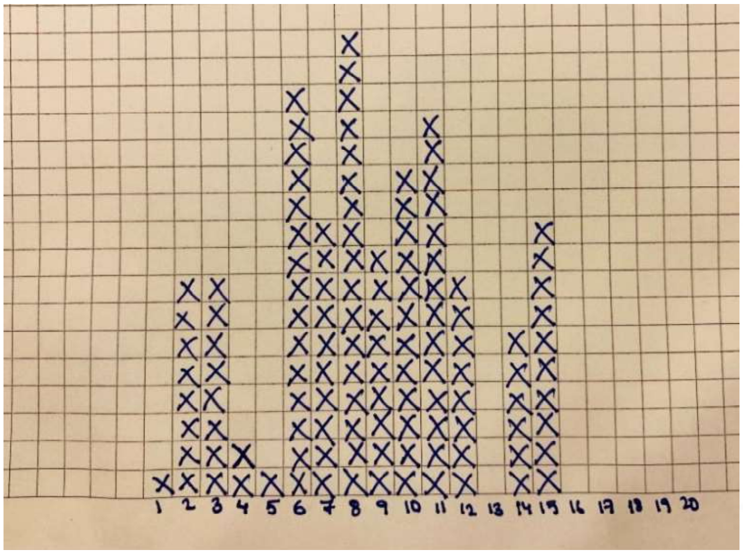

Figure 4.2 A Histogram plotted to find D after survey

The R.L's of each point is calculated and tabulated in an excel sheet. figure 3.2 are the R.L's of stretch 1(left lane). the same are plotted into a histogram as shown in figure 4.2.

The relation between **D** and **IRI** is obtained from the graph – figure 4.3.

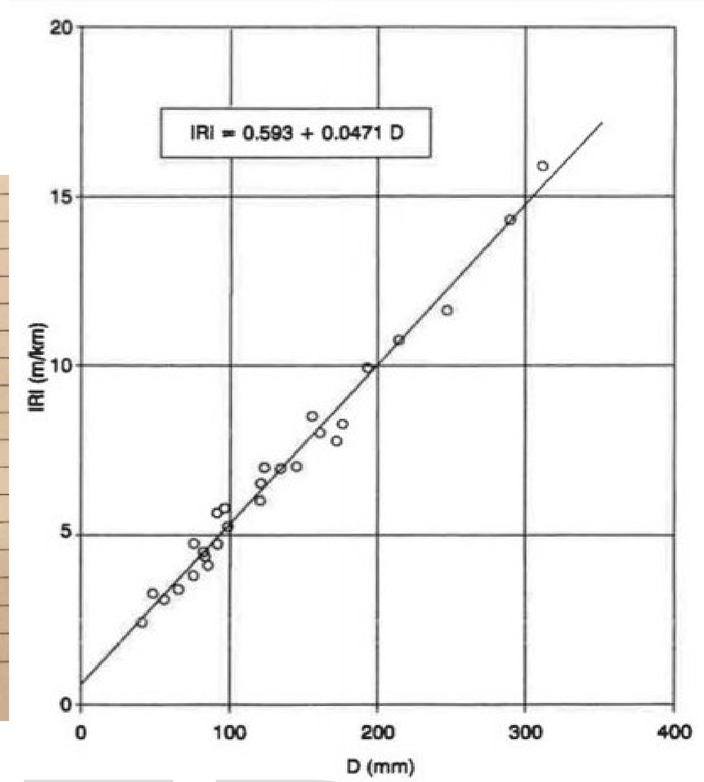

Figure 4.3 Graph of IRI vs D

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For stretch 1 – left lane:

D = 14mm

IRI = 0.593+ 0.0471(D) **(Eq. A1)**

IRI = 0.593+0.0471(14)

= 1.252 m/km

IRI for the left lane (first stretch) = 1252 mm/km

Similarly, calculations are carried out for the rest of the stretches and results are as follows:

STRETCH NO.	LANE	D (mm)	IRI (mm/Km)
1	LEFT	14	1252
	RIGHT	11	1111
2	LEFT	45	2712
	RIGHT	48	2853
3	LEFT	33	2147
	RIGHT	36	2288

Table No. 4.1 International Roughness Index.

5 Finding Vehicle Operating Cost

GENERAL:

The costs associated with owning, operating, and maintaining a vehicle and include fuel consumption, oil and lubrication, tire wear, repair and maintenance, depreciation, and license and insurance [7]. Lesser the roughness index lesser, the vehicle operating cost.

Modelling to obtain Vehicle Operating Cost: HDM[14]-3 VOC[15] MODEL. Highway Design and Maintenance Standard Model (HDM-3) developed by the World Bank. Road User Costs Model is a model designed to compute, for different vehicle types and road conditions, vehicle speeds, fuel consumption, vehicle operating costs, passenger time costs, emission and accident costs based on the Highway Development and Management Model (HDM-3) relationships.

Research at is conducted in various countries over the last 15 – 20 years has demonstrated that road roughness has a significant impact on vehicle operating cost (VOC). HDM-III contains a set of relationships, which estimate the various components of VOC, for example, fuel consumption, tire wear, maintenance, and depreciation, as a function of road roughness. Roughness, in turn, is measured in terms of the IRI.

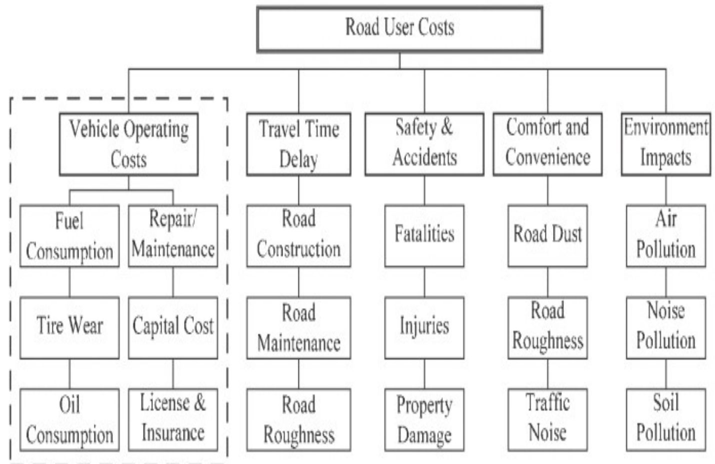

Figure 5.1 Road User Costs.

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Finding out VOC for every model is as follows:

PC – Passenger car

LT – light truck

MT – medium truck

HT – heavy truck

LB – light bus

HB – heavy bus

The following relationship was developed for estimating the VOC:

VOC_{PC}:3.40 – 0.07071RI + 0 .0232(IRI)*2. (**Eq. B1**)

VOC_{LT}: 3.03- 0.0687IRI + 0 .0221(IRI)*2. **(Eq. B2)**

VOC_{LB}: 3.72 – 0.08641RI + 0.0254(IRI)*2. **(Eq. B3)**

VOC_{MT}: 4.32 – 0.0600IRI+ 0 .0I84(IRI)*2. **(Eq. B4)**

VOC_{HT}: 5.57- 0.1543IRI + 0.0411(IRI)*2. **(Eq. B5)**

VOC_{HB}: 17.11 – 0.I522IRI + 0 .0570(IRI)*2. **(Eq. B6)**

[14] HDM-III - Highway Design and Maintenance Standards Model.

[15] VOC – Vehicle Operating Cost.

Where VOC: vehicle operating cost in (Baht/vehicle/km)
IRI – roughness (m /km)

For Left Part of 1st Stretch (L1):

VOC_{PC}:3.40 – 0.07071RI + 0 .0232(IRI)*2.
: 3.40 – 0.07070(1.252) + 0.0232 (1.252)*2
: 3.3478 Baht[16]/vehi/km

VOC_{LT}: 3.03- 0.0687IRI + 0 .0221(IRI)*2.
: 3.03- 0.0687(1.252) + 0 .0221(1.252)*2
: 2.9786 Baht/vehi/km

VOC_{LB}: 3.72 – 0.08641RI + 0.0254(IRI)*2.
: 3.72 – 0.0864(1.252)+ 0.0254(1.252)*2
: 3.6516 Baht/vehi/km

VOC_{MT}: 4.32- 0.0600(1.252)+ 0 .0I84(1.252)*2.
: 4.32 – 0.0600(1.252)+ 0 .0I84(1.252)*2
: 4.2737 Baht/vehi/km

VOC_{HT}: 5.57- 0.1543IRI + 0.0411(IRI)*2.
: 5.57- 0.1543(1.252) + 0.0411(1.252)*2
: 5.4412 Baht/vehi/km

VOC_{HB}: 17.11 – 0.I522IRI + 0 .0570(IRI)*2.
: 17.11 – 0.I522(1.252) + 0 .0570(1.252)*2
: 17.008 Baht/vehi/km

Similarly, calculations are carried out for the rest of the stretches and results are as follows:

STRETCH NO	LANE	IRI (m/km)	VOC_{PC} (baht/ vehi/ km)	VOC_{LT} (baht/ vehi/ km)	VOC_{LB} (baht/ vehi/ km)	VOC_{MT} (baht/ vehi/ km)	VOC_{HT} (baht/ vehi/ km)	VOC_{HB} (baht/ vehi/ km)
1	L	1.252	3.3478	2.9786	3.6516	4.2737	5.4412	17.0087
	R	1.111	3.3500	2.9809	3.6553	4.2760	5.4493	17.0112
2	L	2.712	3.3788	3.0062	3.6724	4.2926	5.4538	17.1164
	R	2.853	3.3871	3.01388	3.6802	4.2985	5.4643	17.1397
3	L	2.147	3.3551	2.9843	3.6515	4.2759	5.4281	17.0459
	R	2.288	3.3596	2.9885	3.6552	4.2790	5.4321	17.0601

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Table No. 5.1 VOC (Baht/vehicle/km)

The given equation gives the VOC in Baht/vehicle/km, hence converting the value to Rs/vehicle/km.
1 Baht = 2.35 INR (As of 12th may).

STRETCH NO	LANE	IRI (m/km)	VOC_{PC} (Rs/ vehi/ km)	VOC_{LT} (Rs/ vehi/ km)	VOC_{LB} (Rs/ vehi/ km)	VOC_{MT} (Rs/ vehi/ km)	VOC_{HT} (Rs/ vehi/ km)	VOC_{HB} (Rs/ vehi/ km)
1	L	1.252	7.88	7.01	8.60	10.06	12.81	40.02
	R	1.111	7.89	7.02	8.60	10.07	12.83	40.05
2	L	2.712	7.95	7.08	8.65	10.11	12.84	40.29
	R	2.853	7.97	7.09	8.66	10.12	12.86	40.30
3	L	2.147	7.90	7.03	8.60	10.07	12.78	40.13
	R	2.288	7.91	7.04	8.60	10.07	12.79	40.16

[17] Baht – it is the official currency of Thailand. This model was developed accordingly using Thailand's currency.

Table No. 5.2 VOC (Rs/vehicle/km)

6 CONCLUSION

Roughness is an important aspect of pavement condition that significantly affects driver comfort and moreover, user cost. After the construction of a pavement system, deterioration occurs because of traffic loading and weathering action and results in the formation of various types of distresses and an increase in pavement roughness. "Roughness" can be defined as irregularities of pavement surface that affect driver safety and increase user costs, including fuel consumption, repair and maintenance, depreciation, and tire costs [6]. In this paper, pavement roughness was calculated with the use of Dumpy level and levelling staff. It has been shown from the survey that it is desirable to keep the unevenness index low.

For road stretch No. 1, the IRI[17] values were found out to be less than 1500mm/km. For road stretch No. 2, the IRI values were found out to be less than 3500mm/km. For road stretch No. 3, the IRI values were found out to be less than 2500mm/km. After estimating the Vehicle Operating Costs, it can be concluded that the road stretch with the least IRI values have fewer vehicle operating costs and the road stretch with the highest IRI have greater vehicle operating costs.

APPENDIX - A

The equation (Eq. A1) is taken from S.K. Khanna and C.E.G. Justo, “Highway Engineering” book, it is an empirical formula which gives the relationship between IRI and D (distance) which is obtained from the histogram by performing the level surveying using dumpy level.

APPENDIX- B

The empirical formulae (Eq. B 1-6) were modelled by HDM-III model. It determined relationships, which estimate the various components of VOC, for example, fuel consumption, tire wear, maintenance, and depreciation, as a function of road roughness. Roughness, in turn, is measured in terms of the IRI. It was modelled for different types of vehicles i.e., Passenger car, Light truck, medium truck, Heavy truck, Light bus, Heavy bus.

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