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Typical Unpaved Roads Roughness Predicted By the HDM-III Model

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The Highway Design and Maintenance Standards Model,[1], HDM-III, based on the Brazil-UNDP field study conducted between 1976 and 1981, predicts the average annual road roughness of engineered unpaved roads as a function of five variables - traffic volume, material properties, road geometry, environment and grading frequency. This note presents examples of HDM-III predictions for a lateritic gravel road and for an earth road, and may be used more generally as a guide for the estimation of roughness of unpaved roads when more precise measurements are not available.

INTRODUCTION

Roughness is the irregularity of the road surface; it affects the dynamics of moving vehicles, wear of vehicle parts, and the handling of a vehicle – safety, comfort and speed of travel - and hence may have a considerable impact on vehicle operating costs. Road agencies need a measure of the roughness of roads as an input to pavement management systems, and whenever the economic feasibility of proposed expenditures on maintenance or upgrading is to be determined. Roughness is measured using the International Roughness Index (IRI) which is a mathematically defined summary statistic of the longitudinal profile in the wheelpaths of a traveled road surface. The IRI describes a scale of roughness which is zero for a true planar surface, increasing to about 2 for paved roads in good condition, 6 for a moderately rough paved roads, 12 for a extremely rough paved roads, and up to about 20 for extremely rough unpaved roads.

On paved roads; roughness increases continuously during a year if maintenance is not applied, roughness is generally measured with a roughness measurement instrument, and this measurement is sufficient to characterize the average annual roughness. On unpaved roads, roughness varies over a year as a function of the season, the changing location of the wheelpaths chosen by the vehicles, and the number and the effects of gradings and other maintenance activities. Therefore, a roughness measurement at a given point in time is not sufficient to characterize the average annual roughness of unpaved roads. Also, due to the fragility of various roughness measurement instruments, these are usually not deployed on unpaved roads, thus forcing road agencies to define the average annual road roughness of unpaved road by other means.

THE STUDY

HDM-III demonstrates that under regular grading maintenance, the cycle of roughness progression and roughness reduction due to maintenance assumes a kind of steady-state[2]. HDM-III predicts an upper limit of roughness, when no grading is done, and a lower limit of roughness, below which further grading would not reduce roughness. The average roughness during a year is computed by combining the roughness progression and grading-effect relationships.

This note presents examples of HDM-III predictions of roughness for engineered unpaved roads, using five variables – material properties, traffic, terrain, environment and grading frequency.

(i) Material Properties. The note covers two types of material – lateritic gravel and earth – with gradations as follows, representing the mean properties of the unpaved roads surveyed on the Brazil-UNPP Study.

	Gravel	Earth
Maximum particle size (mm)	21.9	4.8
Percent passing 2.0 mm sieve (%)	51.1	90.5
Percent passing 0.425 mm sieve (%)	41.6	84.9

Percent passing 0.075 mm sieve (%)	25.5	70.2
Plasticity index	10.1	15.8

(ii) Traffic. Six traffic levels are covered: 5, 25, 50, 100, 200, and 300 AADT, with 70 percent trucks/buses.

(iii) Terrain. Three classes of 'terrain' are defined in terms of the average horizontal curvature of the road.

Terrain	Curvature
Flat and level terrain	50 degrees/km
Rolling and hilly terrain	250 degrees/km
Mountainous terrain	500 degrees/km

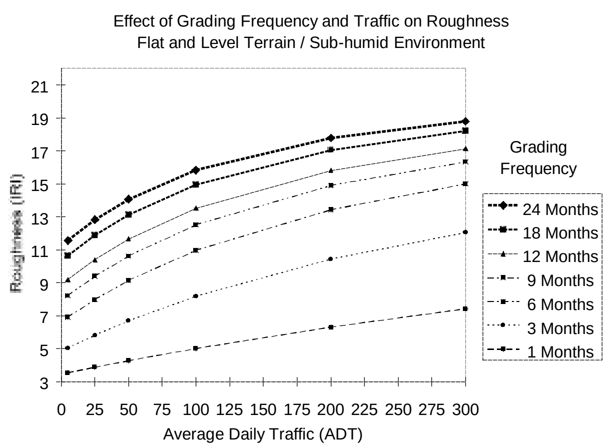
(iv) Environment. Four climatic 'environments' are defined in terms of average yearly rainfall.

Environment	Rainfall
Arid environment	24 mm/year
Semi-arid environment	240 mm/year
Sub-humid environment	960 mm/year
Humid environment	1800 mm/year

(v) Grading Frequency. Seven intensities of grading are covered, ranging from monthly grading, to grading once every twenty-four months.

EXAMPLE 1

This example indicates roughness values for a gravel road with variable traffic and grading frequencies, but with 'terrain' and 'environment' held constant



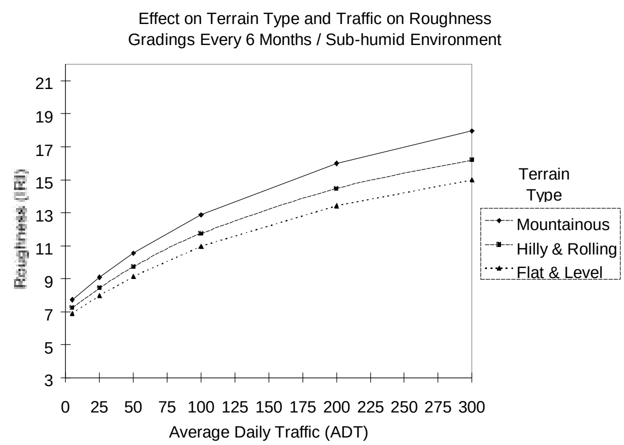
(flat/level terrain and sub-humid environment)

Figure 1 –Grading Frequency Effect on Roughness

Note that the range of roughness varies from 3.5 to 20.0 IRI, and that the grading frequency has a significant impact of roughness, particularly for the more frequent gradings.

EXAMPLE 2

This example indicates roughness values for a gravel road with variable traffic and terrain, but with grading



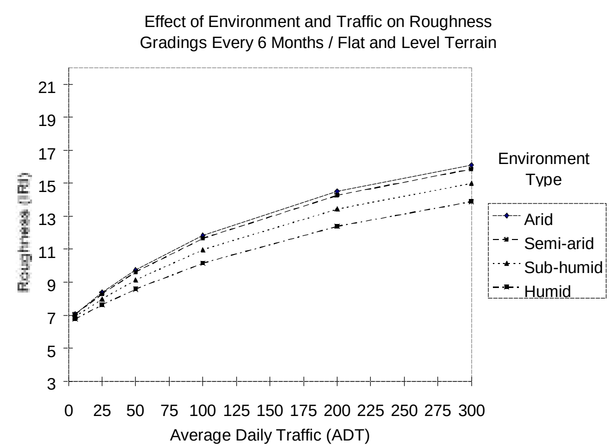
and environment held constant (grading every six months, and sub-humid environment).

Figure 2 – Terrain Type Effect on Roughness

Note that, for a given traffic, roads on a mountainous terrain have higher roughness than roads on flat and level terrain.

EXAMPLE 3

In this example of a gravel road, roughness is presented



as a function of traffic and environment, with grading intensity and terrain type held constant (grading every six months and flat/level terrain).

Figure 3 – Environment Type Effect on Roughness

Note that roads in a humid environment have lower roughness than roads on in arid environment because of increased compaction of the moistened running surface under traffic. The HDM research suggests that there is an additional constraint to vehicle speeds in a humid environment that is not being explained by the roughness alone. This additional constraint has not yet been quantified.

EXAMPLE 4

Example 4 brings together the effects of all variables - Table 1 for lateritic gravel roads and Table 2 for earth roads.

Note that, with all other variables held constant, the roughness of earth roads, because of the smaller particle size, is lower that of gravel roads, but this apparently favorable factor is offset by the difficulty in transiting earth roads during the rainy season.

Roads with materials of different properties are predicted to have different roughness. For example, compared with the lateritic gravel defined above, quartzitic gravels, on average, exhibit a 5% higher roughness and gravels with a maximum particle size of 50 mm exhibit a 30% higher roughness.

CONCLUSION

This note presents examples of HDM-III predictions of roughness for unpaved roads for a series of material properties, traffic levels, terrain types, environment types, and grading frequencies to assist road planners and engineers on their task of defining the roughness of unpaved roads.

The HDM-III predictions are designed primarily for engineered unpaved roads, of either gravel or earth surfacing, because the empirical models are based on a variety of such roads. If necessary, it would be permissible to use the predictions, above, to approximate the properties of unpaved roads that have not been engineered ("tracks"), but the user would need to be aware that the environmental effects of drainage and rainfall may be poorly represented in the models.

The deterioration of engineered unpaved roads can be examined in greater detail using the HDM-III model, the HDM-4 model, or the DETOUR Excel model, which is customized for this purpose and which can be obtained on the Internet at:

http://www.worldbank.org/html/fpd/transport/roads/tools.htm

Information regarding unpaved roads roughness estimation by subjective evaluation can be found on the Rural Transport Technical Note RT-2.

TO LEARN MORE

1. Watanatada, Thawat, et al. 1987. The Highway Design and Maintenance Standards Model. Volume 1, Description of the HDM-III Model. The World Bank, Washington, DC

2. William D.O. Paterson, A. 1987. Road Deterioration and Maintenance Effects, The Highway Design and Maintenance Standards Series. The World Bank, Washington, DC.

Transport Infrastructure Notes *are available on-line at:*
http://www.worldbank.org/html/fpd/transport/publicat/pub_main.htm

Urban Infrastructure Notes *are available on-line at:*
http://www.worldbank.org/html/fpd/urban/publicat/pub_note.htm

Example 4, Table 1: Typical Lateritic Gravel Roads Roughness Levels (IRI)

		Arid Environment			Semi-arid Environment			Sub-humid Environment			Humid Environment		
Traffic (ADT)	Frequency of Gradings (months)	Flat & Level Terrain	Rolling & Hilly Terrain	Mountainous Terrain	Flat & Level Terrain	Rolling & Hilly Terrain	Mountainous Terrain	Flat & Level Terrain	Rolling & Hilly Terrain	Mountainous Terrain	Flat & Level Terrain	Rolling & Hilly Terrain	Mountainous Terrain
5	1	3.6	3.7	3.9	3.6	3.7	3.9	3.5	3.6	3.7	3.5	3.5	3.6
5	3	5.1	5.5	6.0	5.1	5.5	5.9	5.0	5.2	5.5	4.9	5.0	5.1
5	6	7.1	7.7	8.5	7.0	7.6	8.3	6.9	7.2	7.7	6.8	6.9	7.1
5	9	8.4	9.2	10.1	8.4	9.0	9.9	8.2	8.6	9.2	8.0	8.2	8.4
5	12	9.4	10.2	11.3	9.3	10.1	11.0	9.2	9.6	10.3	9.0	9.1	9.4
5	18	10.9	11.8	13.0	10.8	11.7	12.8	10.6	11.2	11.9	10.4	10.6	10.9
5	24	11.8	12.9	14.2	11.8	12.7	13.9	11.6	12.1	13.0	11.3	11.5	11.9
25	1	4.0	4.2	4.5	4.0	4.2	4.4	3.9	4.0	4.1	3.8	3.8	3.9
25	3	6.1	6.6	7.3	6.0	6.5	7.1	5.8	6.1	6.5	5.6	5.6	5.8
25	6	8.4	9.3	10.3	8.3	9.1	10.0	8.0	8.4	9.1	7.6	7.7	8.1
25	9	9.8	10.9	12.2	9.7	10.7	11.8	9.4	9.9	10.7	9.0	9.1	9.5
25	12	10.9	12.0	13.5	10.8	11.8	13.1	10.4	11.0	11.9	10.0	10.1	10.6
25	18	12.4	13.7	15.4	12.3	13.4	14.9	11.9	12.6	13.6	11.4	11.6	12.1
25	24	13.4	14.8	16.6	13.2	14.5	16.1	12.8	13.6	14.7	12.3	12.5	13.1
50	1	4.5	4.8	5.1	4.4	4.7	5.0	4.3	4.4	4.6	4.1	4.1	4.2
50	3	7.1	7.9	8.8	7.0	7.7	8.5	6.7	7.1	7.6	6.3	6.4	6.6
50	6	9.8	10.9	12.3	9.6	10.6	11.9	9.1	9.7	10.6	8.6	8.7	9.1
50	9	11.3	12.6	14.3	11.1	12.3	13.8	10.6	11.3	12.3	10.0	10.2	10.7
50	12	12.4	13.8	15.6	12.2	13.5	15.1	11.6	12.4	13.5	11.0	11.2	11.7
50	18	13.9	15.5	17.6	13.7	15.2	17.0	13.1	14.0	15.2	12.5	12.7	13.3
50	24	14.8	16.6	18.8	14.6	16.2	18.2	14.1	15.0	16.3	13.4	13.6	14.3
100	1	5.4	5.8	6.4	5.3	5.7	6.2	5.0	5.2	5.6	4.7	4.7	4.9
100	3	8.9	10.0	11.3	8.7	9.7	10.8	8.2	8.7	9.5	7.5	7.7	8.0
100	6	11.9	13.4	15.3	11.6	13.0	14.7	11.0	11.7	12.9	10.1	10.3	10.9
100	9	13.4	15.2	17.4	13.2	14.8	16.7	12.5	13.4	14.7	11.6	11.9	12.5
100	12	14.5	16.3	18.7	14.2	15.9	18.0	13.5	14.5	15.9	12.7	12.9	13.6
100	18	15.9	18.0	20.6	15.7	17.5	19.9	15.0	16.0	17.6	14.1	14.4	15.1
100	24	16.8	19.0	21.8	16.5	18.5	21.0	15.8	17.0	18.7	15.0	15.3	16.1
200	1	6.9	7.6	8.5	6.8	7.4	8.2	6.3	6.7	7.2	5.8	5.8	6.1
200	3	11.4	12.9	14.8	11.2	12.5	14.2	10.4	11.2	12.3	9.5	9.7	10.2
200	6	14.5	16.5	19.1	14.3	16.1	18.3	13.4	14.5	16.0	12.4	12.7	13.4
200	9	16.0	18.2	21.0	15.7	17.7	20.3	14.9	16.1	17.8	13.9	14.2	15.0
200	12	16.9	19.2	22.2	16.6	18.7	21.4	15.8	17.1	18.9	14.8	15.1	16.0
200	18	18.1	20.6	23.8	17.8	20.1	23.0	17.1	18.4	20.4	16.1	16.4	17.4
200	24	18.7	21.4	24.8	18.5	20.9	24.0	17.8	19.2	21.3	16.8	17.2	18.2
300	1	8.2	9.1	10.3	8.0	8.8	9.9	7.4	7.9	8.6	6.7	6.8	7.1
300	3	13.2	15.0	17.2	12.9	14.5	16.6	12.1	13.0	14.3	11.0	11.2	11.8
300	6	16.1	18.4	21.3	15.9	17.9	20.5	15.0	16.2	18.0	13.9	14.2	15.0
300	9	17.4	19.9	23.1	17.2	19.4	22.3	16.3	17.7	19.6	15.3	15.6	16.5
300	12	18.2	20.8	24.1	17.9	20.3	23.3	17.1	18.5	20.6	16.1	16.5	17.4
300	18	19.2	22.0	25.5	18.9	21.4	24.6	18.2	19.7	21.9	17.2	17.6	18.7
300	24	19.7	22.6	26.2	19.5	22.1	25.4	18.8	20.3	22.6	17.9	18.3	19.4

	Material Properties
Maximum particle size (mm)	21.9
Percent passing 2.0 mm sieve (%)	51.1
Percent passing 0.425 mm sieve (%)	41.6
Percent passing 0.075 mm sieve (%)	25.5
Plasticity index	10.1

Example 4, Table 2: Typical Earth Roads Roughness Levels (IRI)

		Arid Environment			Semi-arid Environment			Sub-humid Environment			Humid Environment		
Traffic (ADT)	Frequency of Gradings (months)	Flat & Level Terrain	Rolling & Hilly Terrain	Mountainous Terrain	Flat & Level Terrain	Rolling & Hilly Terrain	Mountainous Terrain	Flat & Level Terrain	Rolling & Hilly Terrain	Mountainous Terrain	Flat & Level Terrain	Rolling & Hilly Terrain	Mountainous Terrain
5	1	2.4	2.5	2.7	2.3	2.5	2.7	2.3	2.4	2.5	2.3	2.3	2.4
5	3	4.1	4.6	5.1	4.1	4.5	5.0	4.0	4.3	4.6	3.9	4.0	4.2
5	6	6.3	7.0	7.8	6.2	6.8	7.6	6.1	6.5	7.0	5.9	6.0	6.3
5	9	7.7	8.5	9.5	7.6	8.4	9.3	7.5	7.9	8.6	7.3	7.4	7.7
5	12	8.7	9.6	10.7	8.6	9.4	10.4	8.4	8.9	9.6	8.3	8.4	8.7
5	18	10.1	11.1	12.4	10.0	10.9	12.1	9.8	10.4	11.2	9.6	9.8	10.2
5	24	11.0	12.1	13.4	10.9	11.9	13.1	10.7	11.3	12.2	10.5	10.7	11.1
25	1	2.8	3.1	3.4	2.8	3.0	3.3	2.7	2.8	3.0	2.5	2.6	2.7
25	3	5.1	5.7	6.5	5.0	5.6	6.3	4.8	5.1	5.6	4.5	4.6	4.9
25	6	7.5	8.5	9.7	7.4	8.2	9.3	7.1	7.6	8.3	6.7	6.9	7.2
25	9	8.9	10.1	11.5	8.8	9.8	11.1	8.5	9.1	10.0	8.1	8.3	8.7
25	12	9.9	11.2	12.7	9.8	10.9	12.3	9.5	10.1	11.1	9.1	9.3	9.7
25	18	11.3	12.7	14.4	11.2	12.4	14.0	10.9	11.6	12.6	10.4	10.6	11.1
25	24	12.2	13.7	15.5	12.1	13.4	15.1	11.7	12.5	13.6	11.3	11.5	12.0
50	1	3.3	3.7	4.1	3.3	3.6	4.0	3.1	3.3	3.5	2.9	2.9	3.1
50	3	6.1	7.0	8.1	6.0	6.8	7.7	5.7	6.1	6.7	5.2	5.4	5.7
50	6	8.7	10.0	11.5	8.6	9.7	11.1	8.1	8.8	9.7	7.6	7.8	8.2
50	9	10.2	11.6	13.4	10.1	11.3	13.0	9.6	10.3	11.4	9.0	9.2	9.7
50	12	11.2	12.7	14.7	11.0	12.4	14.1	10.5	11.3	12.5	10.0	10.2	10.7
50	18	12.5	14.3	16.4	12.4	13.9	15.9	11.9	12.8	14.1	11.3	11.5	12.1
50	24	13.3	15.2	17.4	13.2	14.8	16.9	12.7	13.6	15.0	12.1	12.3	13.0
100	1	4.3	4.8	5.5	4.2	4.6	5.2	3.9	4.1	4.5	3.5	3.6	3.8
100	3	7.8	9.0	10.5	7.7	8.7	10.1	7.1	7.7	8.6	6.5	6.6	7.0
100	6	10.6	12.3	14.4	10.4	11.9	13.8	9.8	10.6	11.9	9.0	9.2	9.8
100	9	12.1	13.9	16.2	11.9	13.5	15.6	11.2	12.2	13.6	10.4	10.7	11.3
100	12	12.9	14.9	17.4	12.8	14.5	16.8	12.1	13.1	14.6	11.3	11.6	12.3
100	18	14.2	16.3	19.0	14.0	15.9	18.4	13.3	14.5	16.1	12.6	12.9	13.6
100	24	14.9	17.2	20.0	14.7	16.7	19.3	14.1	15.3	17.0	13.3	13.6	14.4
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200	6	12.9	15.1	17.8	12.7	14.6	17.1	11.9	13.1	14.7	11.0	11.3	12.0
200	9	14.2	16.5	19.5	14.0	16.0	18.7	13.2	14.4	16.2	12.3	12.6	13.4
200	12	14.9	17.4	20.5	14.7	16.9	19.7	14.0	15.3	17.2	13.1	13.4	14.3
200	18	15.9	18.5	21.8	15.7	18.0	21.0	15.0	16.4	18.4	14.1	14.5	15.5
200	24	16.4	19.2	22.6	16.2	18.7	21.8	15.6	17.0	19.1	14.7	15.1	16.1
300	1	7.1	8.2	9.6	6.9	7.9	9.1	6.3	6.9	7.7	5.6	5.7	6.1
300	3	11.8	13.7	16.2	11.5	13.3	15.5	10.7	11.7	13.2	9.7	10.0	10.6
300	6	14.3	16.7	19.8	14.1	16.2	19.0	13.3	14.5	16.4	12.3	12.6	13.5
300	9	15.3	18.0	21.2	15.1	17.5	20.4	14.4	15.8	17.8	13.4	13.8	14.8
300	12	16.0	18.7	22.1	15.7	18.2	21.3	15.0	16.5	18.6	14.1	14.5	15.5
300	18	16.7	19.6	23.2	16.6	19.1	22.4	15.9	17.4	19.6	15.0	15.4	16.5
300	24	17.2	20.1	23.8	17.0	19.6	23.0	16.3	17.9	20.2	15.5	16.0	17.1

	Material Properties
Maximum particle size (mm)	4.8
Percent passing 2.0 mm sieve (%)	90.5
Percent passing 0.425 mm sieve (%)	84.9
Percent passing 0.075 mm sieve (%)	70.2
Plasticity index	15.8