Gradient Determination For The Design of Electrical Autorickshaws Specific to Terrain Characteristics of Kerala State, Using Digital Elevation Model

R. Anil, R. Sabu and T. M. Sreelakshmi

May 30, 2020

Gradient Determination For The Design of Electrical Autorickshaws Specific to Terrain Characteristics of Kerala State, Using Digital Elevation Model

Anil R
Associate Prof. Dept of Civil Engineering
College Of Engineering Trivandrum
Thiruvananthapuram, India
e-mail: anilragunathan@rediffmail.com
*http://www.icite.org/committees.html

Sabu R, Sreelakshmi T M
Department of Civil Engineering
College Of Engineering Trivandrum
Thiruvananthapuram, India
e-mail: cyriacsabu@gmail.com

***Abstract*— Intermediate Public Transport (IPT) in Kerala consists of autorickshaws (diesel and petrol engine powered), which leads to higher emissions and vehicular pollution. In the above context, the state of Kerala plans to transform its IPT fleet by introducing E-autos in the city and restrict growth of diesel/petrol based autos. The State is unique because of its terrain and user base. E-autos now on production have only 7 degree gradeability. Therefore, it is essential to have a technically sound strategy to promote such vehicles. ArcGIS software and Digital Elevation Model (DEM) is used to study the terrain condition of each district. Gradient of road network of each is analyzed. The slope and the total length of road within each particular slope value are measured. Thereby the district-wise distribution of different gradients according to the total length of slope was determined. Based on which the gradeability for the E-autos to be designed has been arrived to have maximum accessibility.**

Keywords- gradient; DEM; GPS; electric autorickshaw; E-autos

I. INTRODUCTION

India's public transport systems are among the most heavily used in the worlds. India's transport crisis has been exacerbated by the extremely rapid growth leads to congestion, noise, pollution and accidents [6]. In passenger transportation the auto-rickshaws have been the mostly utilized form that operates for both medium and short distance commute. Auto-rickshaws are three wheeled vehicles that are extensively used in many Asian countries as taxis of people (3 pax maximum) and goods. Due to poor vehicle maintenance and the use of inefficient two or four stroke engine with very little pollution control, autorickshaws present a grave pollution in major Indian cities [7].

Electric vehicles may be considered the alternative fuel vehicles with lowest air pollution [2]. According to R. Ramanathan et al. [8] the studies project that passenger traffic in India is likely to grow at more than 8% per year and freight traffic at more than 5% per year during the period 1990-2021. This will increase the energy consumption and CO_2 emissions at equivalent rates. The state of Kerala, with over 10 millions on the road, has embraced e-mobility to reduce the impact of pollution from fuel-based vehicles.

The Government of Kerala has chalked out a roadmap for an Electric Vehicle Policy (EVP). Kerala's EVP reduces the number of vehicles with the introduction of Electric buses and Electric autorickshaws (E-autos) thereby providing comfortable public transportation, apart from reduction in air and noise pollution. The Mobility State Level Task Force (e-MobSLTF) has been set up to initiate, develop, and sustain e-mobility in the state. Kerala state is located at the extreme southern tip of the Indian subcontinent and lies between northern latitude of 8º17'30" N and 12º47'40" N and east longitudes 74º27'47" E and 77º37'12" E. The topography consists of a hot and wet coastal plain gradually rising in elevation to the high hills and mountains of the Western Ghats. Electric autorickshaws are now in production by Kerala Automobiles Limited (KAL) a Kerala state Government owned automobile company(Fig 1) and Mahindra (Private Indian company) but they have a gradeability of 7 degrees only. The objective is to analyze the road network of the entire state of Kerala and to study different types of gradient measurement methods. And to assess the slope values of entire road network in Kerala thus arrive at suitable gradeability for which Electric autorickshaw are to be designed.

II. GRADE AND GRADEABILITY

Gradient is the rate of rise or fall along the length of the road with respect to the horizontal. The effect of steep gradient on vehicular speed is considerable. Gradeability is measured in multiple ways such as an angle of inclination to the horizontal (20º,30º,45º,etc), a percentage of rise over run, a ratio of run to some particular number of parts(1 in 20 m,1 in 50 feet,etc).

Figure 1. Electric autorikshaw by KAL

The recommended gradients for different terrain conditions as per Indian Road Congress (IRC) were shown in table 1. Indian Road Congress is a legal document and was set up by Government of India with the objective of enhancing road development in the Country.

III. METHODS ADOPTED

There are many different ways to measure road grade [5]. Clinometers can be used to determine inclination of a road from a vehicle while travelling. Similarly, Digital Elevation Models (DEMs) created from satellites, and aircraft equipped with LiDAR devices, can be used to determine road grade utilizing repeated runs to mitigate error overtime. Also, total station which is used to obtain three dimensional coordinates of every target by measuring the horizontal angle, vertical angle and distance between points is used to determine the gradient of the road [10].

A. Clinometer

An Inclinometer or Clinometer is an instrument used for measuring angles of slope, elevation, or depression of an object with respect to gravity's direction. A digital compass-Clinometer was used for digital acquisition of Gradient. Automatic positioning of measurements is achieved within the app using the mobile phones integrated GPS unit, directly onto preloaded satellite imagery [1]. During the digital compass-clinometer survey, measurements were regularly monitored and compared with traditional compass-clinometer measurements, in accordance with recommended workflows.

B. Total Station

Total station is a surveying instrument combination of the angle measuring capabilities of electronic theodolite and an electronic distance measurement (EDM). Used to determine horizontal angle, vertical angle and slope distance to the particular point. Angles and distances are measured from the total station point to points under survey and coordinates (X, Y and Z or Northing, Easting and Elevation) of the surveyed points with respect to total station points.

TABLE I. GRADIENT CLASSIFICATION AS PER IRC SP 20 - 2002

Terrain	**Ruling Gradient**	**Limiting Gradient**	**Exceptional Gradient**
Plain and rolling	3.3% (1 in 30)	5% (1 in 20)	6% (1 in 16.7)
Mountainous terrain and steep terrain having elevation more than 3000 m above mean sea level	5% (1 in 20)	6% (1 in 16.7)	7% (1 in 14.3)
Steep terrain having elevation more than 3000 m above mean sea level	6% (1 in 16.7)	7% (1 in 14.3)	8% (1 in 12.5)

C. Digital Elevation Model

Digital Elevation Models (DEMs) are three-dimensional (3D) representations of a geographical area which include elevation information. Elevation values can be extracted from a DEM using GPS longitude and attitude points. There are several publicly available DEMs, such as Advances Space-borne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM, Shuttle Radar Topography Mission (SRTM) DEM and JAXA Global ALOS 3D World.

ALOS World 3D is a 30- meter resolution Digital Surface Model(DSM) captured by the Japan region Exploration Agency's(JAXA). The most effective issue concerning is that it is the foremost precise global-scale elevation knowledge currently. It uses the Advanced Land observant Satellite 'DAICHI' (ALOS) supported stereo mapping PRISM. Therefore during this paper JAXA DEM employed to see the road grade.

D. Validating the Results

The measurements of road grade were collected using clinometers, DEM, and total station. Comparing the traditional surveying equipments, total station is able to provide more accurate results in any weather conditions. Hence to validate the results, the measurements were compared with the results obtained through Total Station. Estimates of road grade are provided in percent rise and sampling intervals of 10 m is used [3]. Typically, road grade is presented as a percentage of change in elevation over the horizontal distance. The 10 m sampling interval was selected to dampen the effect of high frequency components on the road grade profile. Distance values were calculated using the distomat

IV. METHODOLOGY

Even total station data gives an accurate result it consumes more time and resources for the extensive data collection and hence we adopt DEM for the data collection. The digitised road network map was collected from NATPAC. There are four different phases for the methodology. (1) Generation of a 3-D road network by connecting 2D road network and a DEM. Esri's ArcGIS 10.3 is used to create 3D road network.

The DEM is a 3D raster dataset available as TIF file for whole state of India, which is manually accommodated to the extent of the study area. To obtain granular result, the 2D road network polylines are interpolated with the DEM to create a 3D feature. (2) GPS traces of multiple trips in both direction is collected. The latitude and longitude of every 10 m intervals are noted and added to the 3D road network.

(3) The elevation value of each GPS points are obtained from JAXA DEM by using the Add Surface Information tool in ArcGIS. According to Margrath et al.(2018) the elevation profile obtained from the source shows significant variations. Hence PostGIS and Savitzky - Golay filtering is used to get a smooth and realistic elevation profile.

(4)Slope map of the road network is prepared and classified according to the IRC recommendation (IRC SP 20-2002)[4] .Thus total length of road network beyond the grade limit is calculated. Fig 2. shows the demonstration of the methodology on Varkala block of Trivandrum district.

V. RESULTS

From college of Engineering Trivandrum to Akkulam of about 2.8 Km stretch was taken as the pilot study area. Total station, Clinometer, GPS along with DEM is used to get the vertical profile of the road. The vertical profile graph thus obtained through DEM and Total station are shown in fig 3 and fig 4 respectively. Comparing the vertical profile obtained through these methods, shows almost similar profile and variations in the profile is due to the low resolution of Digital Elevation Model. This can be improved by using high resolution DEM (We have used a student version). Hence the vertical profile and slope value of entire Kerala state road network can be determined using DEM in a limited time period.

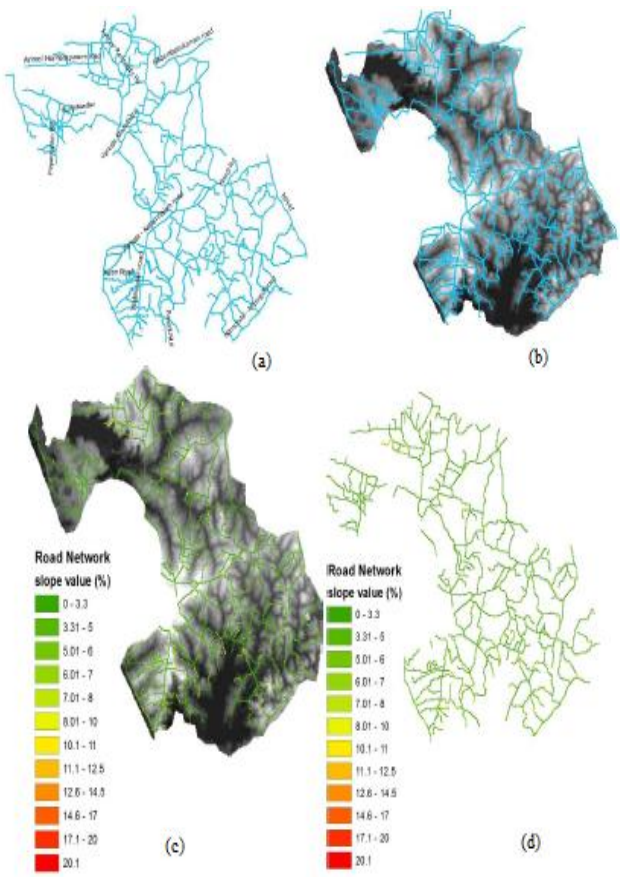

Figure 2. Determination of slope value of varkala block in Trivandrum district of Kerala is demonstrated.(a) road network (b) road network overlayed on DEM (c) Road slope determined through elevation value of DEM (d) Road slope according to IRC SP 20-2002

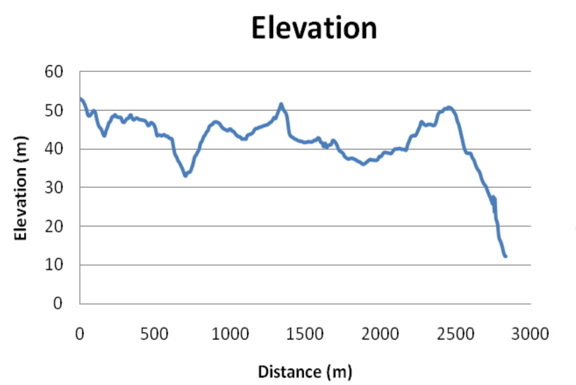

Figure 3. Elevation Vs Distance graph from DEM

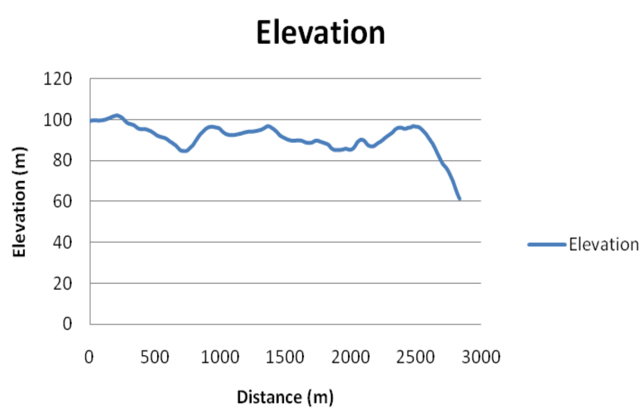

Figure 4. Elevation Vs Distance graph from Total station

District wise Length and percentage of road network that falls within the desirable range i.e.; below 7 % and 7.1 to 12.5 % of Kerala state is shown in table II. And the road network which falls in between 12.51 to 100 % is shown in table III. The maximum percentage of roads as per IRC slope classification range falls in Thiruvananthapuram district (93.89%) and minimum is in Wayanad district (81.5%). Wayanad, Kottayam, Idukki, Kozhikode are the districts having slope value more than 15% hence their terrain is hilly. Electric autorickshaws should be designed according to these changing terrains. The available grade of E- auto is 7% which is inconvenient.

VI. CONCLUSIONS

The auto rickshaw is a common mode of urban transport, both as a vehicle for hire and for private use. Hence the introduction of Electric autorickshaw for the reduction of air and noise pollution is necessary. The design of Electric autorickshaw should be done based on the geography of Kerala which includes rugged and mountainous terrain, rolling hills, coastal plains etc which is different from other states of India. Based on the percent rise of road network obtained from DEM it shows that many district in Kerala have slope value more than 7% hence Electric autoriskshaw should be designed with gradeability more than 7% in Kerala.

Digital elevation model, a 3-D model is used to study about the road network of entire state. It reduces the time consumption, cost of transportation, manual work and also provides similar result to that of Total station. There are several limitation in the study, if the resolution of DEM is high more accurate slope value can be determined and the elevation obtained will be approximately equal to the Total station. For the first time in India a study of this kind is reported for finding gradient using DEM in road networks.

The portion of the road stretches with slope ranges of 12.5-20% although not considerable in quantity, comes in between road stretches with slopes lesser than 12.5% which limits the accessibility of E-autos. E-autos are meant for last mile transportation and should have sufficient gradeability to traverse all grades in the existing road network. Therefore E-autos may be designed for gradeability of 20% (11 degree) in order to provide maximum area of coverage as possible. Length of road network having slope greater than 20% is negligible.

TABLE II. DISTRICT-WISE LENGTH AND PERCENT RISE BETWEEN 0 – 12.5 % OF ROAD NETWORK IN KERALA

Slope value (%) →		**0 – 7**		**7.1 – 12.5**	
District	*Total Length of road (km)*	*Length (km)*	*%*	*Length (km)*	*%*
Thiruvananthapuram	5317.24	5098.57	95.89	180.09	3.39
Kollam	4475.03	4012.42	89.66	404.93	9.05
Pathanamthitta	3906.30	3473.64	88.92	345.20	8.84
Alappuzha	3650.43	3303.32	90.49	333.34	9.13
Kottayam	4385.93	3588.39	81.82	688.24	15.69
Idukki	4859.00	3991.71	82.15	730.54	15.03
Ernakulam	4586.57	4251.10	92.69	306.69	6.69
Thrissur	4552.31	4346.06	95.47	168.53	3.70
Palakkad	5792.21	5294.11	91.40	462.49	7.98
Malappuram	4177.87	3558.77	85.18	518.90	12.42
Kozhikode	3832.89	3191.31	83.26	539.00	14.06
Wayanad	2411.06	1965.01	81.50	336.74	13.97
Kannur	3528.44	3073.88	87.12	345.00	9.78
Kasaragod	3386.28	2979.88	88.00	320.82	9.47

TABLE III. DISTRICT-WISE LENGTH AND PERCENT RISE BETWEEN 12.51 AND 100 % OF ROAD NETWORK IN KERALA

Slope value (%) →		**12.51 - 20**		**20.1 - 100**	
District	*Total Length of road (km)*	*Length (km)*	*%*	*Length (km)*	*%*
Thiruvananthapuram	5317.24	36.75	0.69	1.83	4.98
Kollam	4475.03	56.03	1.25	1.65	2.94
Pathanamthitta	3906.30	86.37	2.21	1.09	1.26
Alappuzha	3650.43	13.66	0.37	0.11	0.81
Kottayam	4385.93	107.12	2.44	2.18	2.04
Idukki	4859.00	134.21	2.76	2.54	1.89
Ernakulam	4586.57	28.78	0.63	0	0.00
Thrissur	4552.31	36.34	0.80	1.38	3.80
Palakkad	5792.21	34.75	0.60	0.86	2.47
Malappuram	4177.87	98.87	2.37	1.33	1.35
Kozhikode	3832.89	100.99	2.63	1.59	1.57
Wayanad	2411.06	107.83	4.47	1.48	1.37
Kannur	3528.44	108.51	3.08	1.05	0.97
Kasaragod	3386.28	83.84	2.48	1.74	2.08

Acknowledgment

The authors gratefully acknowledge Prof. Ashok Jhunjhunwala, Professor Indian Institute of Technology Madras, IITM (Advisor for EV initiatives to Government of Kerala) for providing this research problem to us and for his constant support in successful completion of the work.

References

[1] Cawood, A. J., Bond, C. E., Howell, J. A., Butler, R. W., & Totake, Y. " LiDAR, UAV or compass-clinometer? Accuracy, coverage and the effects on structural models, " Journal of Structural Geology, *98*, pp. 67-82. 2017

[2] G.H. Tzeng, C.W. Lin and S. Opricovic, "Multi-criteria analysis of alternative fuel buses for puvlic transportation", Energy policy, 33(11), pp. 1373-1383,2005

[3] H. Bae, S. Ryu and J. Gerdes, "Road Grade and Vehicle Parameter Estimation for Longitudinal Control using GPS,"Proceedings of the IEEE Conference on Intelligent Transportation Systems, Oakland, CA, pp. 166-171,2001.

[4] Indian Roads Congress special publication 20 – 2002

[5] J. Magrath and M. Brady, "Evaluating different methods for determining road grade best suited to advanced bus transportation systems," 2017 IEEE International Conference on Service Operations and Logistics, and Informatics (SOLI), Bari, 2017, pp. 108-113, doi: 10.1109/SOLI.2017.8120979.

[6] J. Pucher, N. Mittal and N. Ittyerah, "Urban transport crisis in India", Transport policy, 12(3), pp. 185-198, 2005.

[7] P. Mulhall, S.M. Lukic , S.G Wirasingha, Y.J Lee, and A. Emadi, "Solar assisted electric autorickshaw three-wheeler,"IEEE transactions on vehicular technology, 59(5), pp. 2298-2307, 2010

[8] R. Ramanathan and J.K Parikh, "Transport sector in india: an analysis in the context od sustainable development", Transport Policy, 6(1), pp. 35-45, 1999

[9] S. Jiand, C. Wang, C. Zhang, H. Bai and L. Xu, "Adaptice estimation of road slope and vehicle mass of fuel cell vehicle", eTransportation, 2, 100023, 2019

[10] W. Merkle, J.J Myers, "use of the total station for serviceability monitoring of bridges with limited access in Missouri,USA", University of MissouriRolla