Abstract
The growing vehicle population and non-expanding road infrastructure have forced the automobiles to travel under congested conditions including increased stopped delays at intersections. The present capacity of the road networks has reached their optimum level and the urban growth has left no space for expansion of facilities. This condition is one of the reasons for increasing congestion and thereby reducing the Level of Service of roads. Based on the review of the existing literature and evaluation measures of Level of Service (LOS) in national and international perspective, the traffic conditions in the capital town of Port Blair of Andaman & Nicobar Islands, a Union Territory in India, was surveyed and the traffic parameters were subjected to investigation with respect to the inclusion of gradient as a new parameter for evaluating LOS. Thus terrain conditions were taken into account with varying ranges and parameters along with flow and speed to obtain a new relationship with the prevailing road and traffic conditions and the same can be applicable for island places like Port Blair with rolling terrain conditions.

1. Introduction
In the present scenario, the rapid pace of industrialization and economic development has made considerable impact on transportation and the related traffic plying on roads in rural and urban areas and it will continue to do so in coming times. Even though as traffic flow increases, there is
corresponding decrease in speed; it is a stochastic process, with random variations in vehicle and driver characteristics and their interactions [Khisty&Lall, 2006] 25.

India the seventh largest country in the world and second largest in Asia has a population of more than 1027 million and area of 329 million hectares. The consumption of energy in transport sector is 16 percent of total use of energy [Indian Highways, 2006] 10. The growing vehicle population and non-expanding road infrastructure have forced the automobiles to travel under congested conditions including increased stopped delays at intersections.

Capacity of a facility is defined as the maximum hourly rate at which persons or vehicles can reasonably be expected to traverse a point or uniform section of a lane or roadway during a given time period under prevailing roadway, traffic and control conditions. The service which a roadway offers to the road user can vary under different volumes of traffic [Kadiyali.L.R. 2007] 23. The Highway Capacity Manual [HCM, TRB, 1985] has introduced the concept of “Level of Service” (LOS) to denote the level of facility one can derive from a road under different operating characteristics and traffic volume. Capacity and Level of service are two related terms. LOS gives qualitative measure of traffic, whereas capacity analysis gives a quantitative measure of a facility. However, they both vary with the type of facility, prevailing traffic and road conditions etc.

Highway Asset Management guidance Note, UK Roads Board defines LOS as “Levels of Service describe the quality of service provided by the asset for the benefit of customers.”. With regard to composite indicators that reflect the social, economic and environmental goals of the community. Code of Practice for the Maintenance of Highway Structures [UK Roads Board] states LOS as “A statement of the performance of the asset in terms that the stakeholder can understand”. These Levels of Service cover the condition of the asset, as well as non-condition demand aspirations i.e. a representation of how the asset is performing in terms of both delivering the service to stakeholders and maintaining its physical integrity at an appropriate level. Level of Service typically covers condition, availability, accessibility, capacity, amenity, safety, environmental impact and social equity.

1.1 Perspective from Case Study

A study was conducted for the arterial roads of Port Blair, capital town of Andaman and Nicobar Islands for analyzing the traffic parameters and the present Level of Service. Six major roads were selected for the study and the traffic volume data were collected for both peak tourist season (September to January) as well as for off-peak tourist season (February to July). The island population of 3-4 lakh (as per the 2001 census) has its major part, more than 60%, residing in and around the Port Blair town. The total geographical area of these islands is 8300 Square kilometres. These islands spread across the total distance of 780 kilometres and nearly 6400 Square kilometres land area of Andaman group consists of reserve forest and is protected areas. The factors identified for contributing to traffic problem were:

- The width varying from 7 meters to 15 meters from place to place.
- The lanes demarked my road markings.
- Steep gradient roads making grade separated intersections.
- Closely spaced intersections.
- Restricted or absence of right of way
- Increase in vehicular population restricting the speed and capacity.
- Underutilized road stretches connecting to higher volume roads.
In the absence of right of way and limited land space the road traffic requirements are entirely different from mainland India roads. In view of the evident increase in vehicular population, the study was mainly objected on analysis of Level of Service with respect to the gradient due to prevailing terrain, along with speed and flow on the main arterial roads of Port Blair town. Eight major roads were selected for the study (as shown in Figure-1), dividing the Port Blair area into outer and inner cordons and the traffic volume data were collected for both peak tourist season (September to January) as well as for off-peak tourist season (February to July). The LOS prescribed by various guidelines are usually for listed ideal conditions of lane width, shoulder width etc. but in the absence of such road margins and other geometric features the facility can be evaluated for those Level of Service. In case of Port Blair roads, as shown in Figure-1, the rolling terrain and demographic factors with respect to land area available to island population, the roads needs to be assessed differently for preference as well as for land use reasons.

Figure-1.1 Selected Roads of Port Blair for Survey

Therefore to include the gradient component and to rationalize the qualitative designation of Level of service for the roads with varying gradient and different Volume Capacity Ratio (V/C Ratio) a relation was developed and the same was analysed to have a numerical relation between both. Thus for given V/C Ratio, various gradient conditions are matched and according to standards (HCM)
keeping the range of speed and V/C ratio a separate set of LOS has been defined with respect to prevailing gradient of roads.

2. Methodology Adopted for Study

Port Blair town being the capital of Andaman and Nicobar Islands has maximum commercial activities, in terms of developmental programs, as major part of the island population is concentrated in this area. The haphazard expansion of town for various developmental projects have resulted in pockets of settlements, either provided by government or privately constructed, requiring road network for easy accessibility in the rolling terrain of the area. Thus the overloaded main roads (as shown in Figure-1), in which most of them fit into the definition of downtown roads with frequent intersections and busy built up places, feed about 90% of the town traffic gave following scope for study;

i) Selection of roads contributing to maximum amount of traffic flow viz; Modal school Road, Kamraj (VIP) Road, School Line Road, Delanipur road, Middle point road, Junglighat road, Phenix Bay Road and Bengali Club-Light House road.

ii) Data collection which include
   a) Carrying out volume count by manual method- obtaining directional, classification and pedestrian count in the prescribed format recommended by Indian Road Congress (IRC.9-1972) in peak and lean period
   b) Flow measurement in busy stretches during peak and off-peak hours by manual counts along with other traffic parameters
   c) Profile Survey of roads for gradient evaluation
   d) Road length and width measurement for lane capacity assessment.
   e) Evaluating the cross slope for the selected stretch of roads with the prevailing terrain conditions.

iii) Assessment of Level of service as per the prevailing traffic Characteristics and standards

iv) Establishing relationship between Volume Capacity Ratio and Level of Service

3. Analysis of Traffic Flow

Traffic Volume Data was collected for the selected eight routes/roads. All the roads are having single carriageway pattern with road markings distributing the lanes. Hence both the directional flow was taken into account. Comparative analysis for the period of study (peak and off peak hour) as shown below in figures 3.1 to 3.8, gives the pattern for the direction having higher flow volume;

![Figure 3.1- Traffic flow for Middle point road](Image)
S. Raji and Dr. V. L. Narasimha :: Evaluating Level of Service for Gradient in Non-Plain Terrains
S. Raji and Dr. V. L. Narasimha :: Evaluating Level of Service for Gradient in Non-Plain Terrains
4 Comparative Analysis for Capacity & Volume

- The observed traffic volume data was converted into Passenger Car Unit (PCU). Practical capacity i.e the maximum number of vehicle that can pass a given point on a lane or road way during one hour, without traffic density being so great as to cause unreasonable delay, hazard or restriction to the driver’s freedom to manoeuvre under the prevailing roadway and traffic conditions was calculated.

- The graphical representation between volume capacity ratio and PCU was obtained in a single graph as shown from figure 4.1 to 4.8. The blue lines show the averaged traffic volume (in terms of PCU) distribution for the peak and off peak hour’s count for 7 days and the brown line shows the Volume – Capacity (V-C) Ratio.

- Among the selected eight roads the direction of traffic having highest volume was only selected for capacity analysis for both the said reason.

Figure 4.1- Capacity Distribution of traffic for Middle Point road

Figure 4.2- Capacity Distribution of traffic for VKV road
S. Raji and Dr. V. L. Narasimha :: Evaluating Level of Service for Gradient in Non-Plain Terrains

Figure 4.3- Capacity Distribution of traffic for Junglighat road

Figure 4.4- Capacity Distribution of traffic for Kamraj (VIP) road

Figure 4.5- Capacity Distribution of traffic for Bengali Club road
Figure 4.6 - Capacity Distribution of traffic for Delanipur road

Figure 4.7 - Capacity Distribution of traffic for Phoenix Bay road

Figure 4.8 - Capacity Distribution of traffic for Model School road
When compared with other category of vehicles, two wheelers and four wheelers contribute maximum to traffic flow

Middle point, Junglight road, and Bengali club road the situation remains same from morning peak to evening peak. Amongst all the selected roads, Bengali Club road has the steepest gradient whereas other two roads have comparatively flatter terrain. Moreover these stretches have ribbon development with new business properties abutting alongside, the traffic attracted by these stretches are in increasing order. Thus even after the evening peak the volume of traffic is higher as compared to other roads.

5 Analysis of Gradient and traffic Parameters

5.1 Profile Assessment

The gradient for the eight selected road were evaluated through profile survey and cross verified through Google map analysis. The figure 5.1 to 5.7 shows some of the profile for the selected roads

- Figure 5.1 – Longitudinal Section for Model School Road
- Figure 5.2 – Longitudinal Section for Kamraj Road
- Figure 5.3 – Longitudinal Section for VKV Road
5.2 Analysis of Traffic Parameters

Spot speeds were taken during morning and evening peak for all the roads covered under the study. For one direction 40 vehicles were observed and accordingly, assuming 100Km/hr (kilometre per hour) to be the maximum speed that a vehicle could attain/gain, the speed range were selected for frequency distribution and thereafter mean speed was...
evaluated for all the eight selected roads for capacity evaluation. The Speed distribution curves obtained from the data is shown in Figure 5.8 to 5.15

Figure 5.8 – Speed Distribution curve for Model School Road

Figure 5.9 – Speed Distribution for Kamraj (VIP) Road

Figure 5.10 – Speed Distribution curve for Junglighat Road

Figure 5.11 – Speed Distribution curve for V K V Road
5.3 Analysing Level of Service (LOS) with Road Features and Traffic Parameters

The observed gradient (in percentage) for all the selected roads along with the traffic parameters viz; Flow (in vehicles per hour), Model Speed (in Kilometre per hour), Volume Capacity Ratio, carriageway width and length (in meters) and other details are given in Table 5.1. The volume...
survey was carried out for both the directions. The higher value of Model speed is considered for analysis so that Level of Service can be assessed according to the higher value for these downtown roads. Amongst the selected roads only Kamraj Road which is also known as VIP Road has larger length without intercepting intersections which defines it in the category of Arterial Road (HCM). The flow was calculated for both morning and evening peak and the highest values were considered for density and thereafter for calculation of theoretical capacity.

<table>
<thead>
<tr>
<th>SN</th>
<th>Name of the Road</th>
<th>Length in Meters</th>
<th>Width of Carriageway</th>
<th>Gradient (%)</th>
<th>Density</th>
<th>Rate of Flow (q=veh/hr)</th>
<th>Model Speed (km/hr)</th>
<th>Hourly Volume</th>
<th>Volume Capacity Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Modal School Road</td>
<td>290</td>
<td>8.9</td>
<td>2</td>
<td>21</td>
<td>845</td>
<td>40</td>
<td>1345</td>
<td>0.9</td>
</tr>
<tr>
<td>2</td>
<td>Kamraj (VIP) Road</td>
<td>1621.8</td>
<td>9.46</td>
<td>3</td>
<td>19</td>
<td>740</td>
<td>44</td>
<td>1036</td>
<td>0.7</td>
</tr>
<tr>
<td>3</td>
<td>Middle Point Road</td>
<td>680</td>
<td>13.45</td>
<td>3.5</td>
<td>17</td>
<td>782</td>
<td>45</td>
<td>1186</td>
<td>0.7</td>
</tr>
<tr>
<td>4</td>
<td>Bengali Club Road</td>
<td>300</td>
<td>10.95</td>
<td>8.6</td>
<td>18</td>
<td>830</td>
<td>45</td>
<td>2041</td>
<td>1.4</td>
</tr>
<tr>
<td>5</td>
<td>Phoenix Bay Road</td>
<td>990</td>
<td>9.95</td>
<td>5.1</td>
<td>14</td>
<td>630</td>
<td>44</td>
<td>891</td>
<td>0.7</td>
</tr>
<tr>
<td>6</td>
<td>Delanipur Road</td>
<td>720</td>
<td>7.52</td>
<td>4</td>
<td>13</td>
<td>555</td>
<td>44</td>
<td>1117</td>
<td>0.7</td>
</tr>
<tr>
<td>7</td>
<td>Junglighat Road</td>
<td>320</td>
<td>12</td>
<td>1.5</td>
<td>15</td>
<td>700</td>
<td>44</td>
<td>1590</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>School Line (VKV) Road</td>
<td>420</td>
<td>12</td>
<td>1.4</td>
<td>40</td>
<td>1425</td>
<td>36</td>
<td>1904</td>
<td>1</td>
</tr>
</tbody>
</table>

The Level of Service (LOS) as per HCM for downtown road and Arterial road category certifies the roads under study into comparatively higher LOS but with respect to the roads in developed Cities and urban area in India, the Port Blair roads has existing deficiencies in operating conditions which include absence of shoulders, undulated camber, non-uniform width throughout the length, absence of right of way and on street parking with undivided carriageway in downtown road situations.

The demographic situation doesn’t gives a land strip for a width more than 2 kilometres which has restricted the spread of town as well the dependent population. The haphazard distribution of residential pockets, wherein the 50 % of the total population of Andaman & Nicobar Islands is concentrated in and around Port Blair town has made this urban area more congested for any futuristic acquisition of space for expansion of existing road facility. Tourism being the only industry, flourishing due logistically and geographically isolated conditions, the road side development and mushrooming private properties has made infrastructures ever more road dependent resulting more congested parking and reduced carriageway for traffic movement. The figure -5.12 shows the map of Port Blair town with spread of residential area, in the island town
with rolling terrain, which contributes traffic to the selected eight roads. The right side area to VKV road, which appears to be a long open strip, as shown in the figure is the airport area.

![Map of Port Blair showing the spread of residential pocket and the town roads](image)

Figure 5.16- Map of Port Blair showing the spread of residential pocket and the town roads

When the LOS conditions, as given in manuals and Codes, for Freeway segments and Highways are made to develop with a polynomial relation then the graphs obtained with $R^2$ value is shown as graph A & B respectively, in Figure -5.17

**Graph A- for six lane Freeway segment**

$y = -102.93x + 129.63$

$R^2 = 0.8543$

**Graph B – for two lane Highways**

$y = -157.96x + 180.18$

$R^2 = 0.9478$

Figure 5.17- Speed v/s Volume Capacity Ratio graphs for LOS conditions
However the LOS recommended by HCM for downtown roads and arterial roads are different keeping in view the roadside development and land use pattern. It gives the maximum speed of more than 45 Km/hr for LOS-A whereas the minimum LOS of E states for a speed less than 15Km/hr. Though the literature review doesn’t accessed the Volume Capacity (v/c) ratio referred for these LOS for downtown roads by HCM, so simulating the volume capacity ratio conditions given for the above mentioned standard road facilities, the v/c ratio is 0.7,0.8,0.9,0.95,1.0 and 1.5 for LOS A to F respectively. Thus such v/c ratio with recommended speeds for downtown road, different relations was observed when developed in polynomial equation with $R^2$ value, as shown in figure 5.18

\[ y = -33.441x + 55.938 \]
\[ R^2 = 0.7452 \]

Figure 5.14- Speed v/s Volume Capacity Ratio graphs for Downtown roads

The Indian Road Congress (IRC: 106-1990) refers urban roads as sub-arterial roads with fringe conditions like frontage development, bus stops, waiting restrictions etc. Thus all the selected roads will fall in this category only. But since the roads being the main roads of Port Blair town they are considered as downtown roads for study and evaluating LOS with the recommendations as suggested in HCM. Thus for the prevailing traffic conditions and the data collected from the study, the Level of Service attained by the said roads when designated as downtown roads are as given in Table 5.2.

<table>
<thead>
<tr>
<th>SN</th>
<th>Name Of The Road</th>
<th>Model Speed (Km/Hr)</th>
<th>Gradient (%)</th>
<th>V/C Ratio</th>
<th>LOS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Modal School Road</td>
<td>40</td>
<td>2</td>
<td>0.9</td>
<td>B</td>
</tr>
<tr>
<td>2</td>
<td>Kamraj (VIP) Road</td>
<td>44</td>
<td>3</td>
<td>0.7</td>
<td>B</td>
</tr>
<tr>
<td>3</td>
<td>Middle Point Road</td>
<td>45</td>
<td>3.5</td>
<td>0.7</td>
<td>A</td>
</tr>
<tr>
<td>4</td>
<td>Bengali Club Road</td>
<td>45</td>
<td>8.6</td>
<td>1.4</td>
<td>A</td>
</tr>
<tr>
<td>5</td>
<td>Pheonix Bay Road</td>
<td>44</td>
<td>5.1</td>
<td>0.7</td>
<td>A</td>
</tr>
<tr>
<td>6</td>
<td>Delanipur Road</td>
<td>44</td>
<td>4</td>
<td>0.7</td>
<td>A</td>
</tr>
<tr>
<td>7</td>
<td>Junglighat Road</td>
<td>44</td>
<td>1.5</td>
<td>1</td>
<td>A</td>
</tr>
<tr>
<td>8</td>
<td>School Line (VKV) Road</td>
<td>36</td>
<td>1.4</td>
<td>1</td>
<td>B</td>
</tr>
</tbody>
</table>

Table 5.2 Level of Service for Port Blair Roads according to Speed (as per HCM)
6 Inter-relating Road and Traffic Characteristics

As per HCM the Volume Capacity (v/c) Ratio for freeways segments at higher LOS as A will be less than 0.5 with very low density whereas the study revealed that the minimum v/c ratio is 0.7. The road conditions with local area limitations like the ones having with Port Blair roads envisaged this study with new scope of developing a relation between gradient and prevailing Volume Capacity Ratio and the Polynomial equation with \( R^2 = 0.99 \) was developed as shown in figure 6.1.

The x-axis represents the volume capacity ratio whereas the y-axis represents the prevailing gradients. In such rolling terrains the speed being guided by road slopes/gradients rather than prevailing traffic stream conditions, will not be an appropriate parameter, therefore the existing v/c ratio was considered for establishing the relation. The initiative was to attempt moderation of relation between prevailing gradient and v/c ratio since there are varying width one single road stretch. The higher gradient in one particular selected road is giving more v/c ratio not because of the gradient factor but because of the prevailing land use pattern of the said downtown road. On the other hand gentler gradients also indicates v/c ratio as 1.0 for better accommodating space.

\[
y = 35.99x^2 - 68.95x + 34.54
\]
\[
R^2 = 0.9
\]

Therefore the unique localised conditions of Port Blair roads and the above equation stand validated for the following road features:

- Minimum width of road not less than 7.7 meters and maximum 13.5 metres as undivided carriageway
- The minimum gradient not less than 1.4 %
- All the roads are downtown roads with frequent intersections and the length of stretch not more than 1 kilometre
- The maximum attainable speed is not more than 45 Km/hr in prevailing traffic conditions unless the v/c ratio is less than 0.7

Thus following LOS, as given in Table 6.1 can be defined for such roads including gradient as one of the features.
Table 6.1 Level of Service for Gradient Conditions

<table>
<thead>
<tr>
<th>SN</th>
<th>Volume Capacity Ratio</th>
<th>Gradient (%)</th>
<th>LOS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.7</td>
<td>≥ 3</td>
<td>A</td>
</tr>
<tr>
<td>2</td>
<td>0.8</td>
<td>2.40 to 2.99</td>
<td>B</td>
</tr>
<tr>
<td>3</td>
<td>0.9</td>
<td>1.6 to 2.00</td>
<td>C</td>
</tr>
<tr>
<td>4</td>
<td>0.95</td>
<td>1.5 to 1.6</td>
<td>D</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>1.4 to 1.5</td>
<td>E</td>
</tr>
<tr>
<td>6</td>
<td>1.5</td>
<td>&lt; 1.4</td>
<td>F</td>
</tr>
</tbody>
</table>

7 Conclusion

The study gave the scope of developing a new relation between gradient and Level of Service exclusively to the terrain conditions prevailing to Port Blair roads or such similar conditions. Advanced computational tools can be used for further investigation and future research to make co-related relation between LOS and gradient for such hilly/rolling terrains where the road geometrics are far from the standards as prescribed by codes/manuals as the constructional difficulties and alignment challenges predominates the accessibility rather than facilitating features for comfortable riding conditions.

Acknowledgement

The authors are grateful to the students namely Rithu, Arun and Vishal of Civil Engineering Department of Dr.B.R. Ambedkar Institute of Technology, Port Blair, Andaman & Nicobar Islands (A&N Islands), India for having helped us to conduct the profile survey for all the selected roads considered for the study and research. We are also thankful to the Traffic Police Division of Police Department A&N Administration in helping us and providing all support with the Traffic survey during peak and off peak hours.

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