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ASSESSMENT OF VEHICULAR POLLUTION IN DHANBAD CITY USING CALINE 4 MODEL

***Bhawna Dubey[1], Asim Kumar Pal[2] and Gurdeep Singh[3]**
[1]*Amity Institute of Environmental Sciences, Amity University, Noida, India*
[2, 3] *Department of Environmental Science and Engineering, Indian School of Mines, Dhanbad, Jharkhand, India*
**Author For Correspondence*

ABSTRACT
CALINE 4 has several advantages over other line source models and it is used as a base model for the Dhanbad city to predict CO concentration from various categories of vehicles (heavy and light duty). Among various gaseous pollutants emitted from vehicular exhaust carbon monoxide (CO) are chosen for the line source modeling because it is chiefly emitted from vehicular exhausts. In this regard, vehicular count was done at different road network on various traffic intersections to depict the traffic concentration at various road links. Model output (CALINE-4) revealed maximum concentrations of 1.70 ,1.56, 1.46 ppm at Bank More (T4) and 1.54, 1.48 and 1.40 ppm at Railway station (T3) junction followed by 1.43, 1.31 and 1.37 ppm at Mohuda (T6) during three peak traffic situations (9.00 to 10.00 hours, 12.00 to 13.00 hours and 17.00 to 18.00 hours, respectively).

Key Words: *CALINE 4, CO, Vehicular Exhaust*

INTRODUCTION
India has made rapid development in industrialization and it is one of the ten most industrialized nations of the world. The rapid growth is always associated with the transportation, industrialization and the road networks are acting as its life line supporting various vehicular movements on various roads. This development has brought with it surplus and unforeseen consequences such as unplanned urbanization, pollution in terms of generation of noxious gases and particulate emissions and various health impact. This is aggravated by the poor maintenance of vehicles and running of diesel powered vehicles in the coal mining premises outside and the significant number of new age automobiles is expected to contribute towards deterioration of ambient air quality. Recent evidence indicates that motorized vehicles are a major source of air pollution in urban areas, on the other hand transportation engineers aim at steps to reduce congestion and trying to improve the flow conditions at various road network in urban streets; the impact on the environment is neglected and often ignored with the identification of cities like Dhanabd as industrial region emerging as an urban centres. The CPCB (Central Pollution Control Board) in consultation with the Ministry of Environment and Forests Government of India has identified a total of 88 industrial areas in recognition of the severity of environmental pollution in terms of air, water, ecological damage and visual conditions. Among various industrialized area Dhanbad is designated as critically polluted area, it ranks 13 among 88 industrial areas, which scores 78.60 out of scale of 100.The rapid growth of Dhanbad city in terms of population and economic activity related to coal mining (Jharia coalfield) makes it vulnerable to environmental pollution problems.
Air quality models and exposure assessment studies provide a tool to understand the implications of pollutant emissions and aid in deciding control and management strategies. Air dispersion models have been widely used to address this issue by providing invaluable information for better and more efficient air quality planning (Kho *et al.*, 2007).
Modelling of air pollution has been accomplished with the aid of Gaussian Dispersion Plume models that accounted for the temporal and spatial dispersion characteristics of the pollutants. Vehicular emission is generally considered as a line source in air dispersion models. Line source models are used for assessing the effects of roadway emissions (Nagendra and Khare, 2002 and Venkatraman and Horst, 2005). They

are computer-based models that calculate the distribution of the pollutants in the atmosphere from specified emission sources and meteorological scenario. The present research paper, thus, evaluates the application of CALINE 4 in predicting the concentrations of Carbon-mono-oxide (CO) in the study area.

MATERIALS AND METHODS

Pollution Due To Vehicular Activity (Road Traffic)

The vehicular emissions are one of the major sources of air pollution in the study area. Unlike industrial emissions, vehicular pollutants are released at ground level and hence their impacts on the recipient population are likely to be significant. Figure 1 shows the existing mines, road network in the study area and form the basis of air quality modeling. In order to assess vehicular movement and associated air pollution in different roads, consideration was confined to the road networks and traffic junctions only as shown in Table 1.

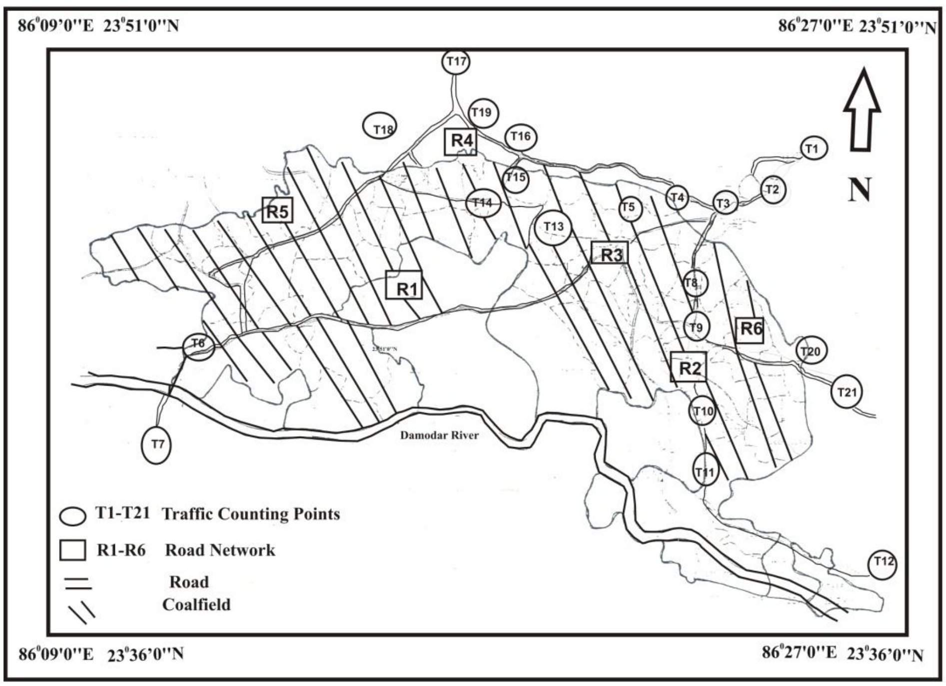

Figure 1: Vehicular Junction Points and Dominant Road Networks in the Study Area

Traffic Counting At Different Road Networks

Total six road link/networks viz., R1, R2, R3, R4, R5 and R6 with twenty one traffic junction points were selected for vehicular pollution source modeling which covers the entire study area. Three hourly average traffic counting was done for different category of vehicles (Light duty, heavy duty) at different junctions through road networks during 6.00 to 21.00 hours during 2008-2009. Field motor vehicle counts were continuously monitored for different categories of vehicles (i.e. heavy duty, light duty petrol and diesel, etc.) for each road network. Based on this database, average daily vehicular movement on the different road networks of the study area was evaluated. A total of 20 discrete receptors (monitoring site) were assessed in terms of potential exposure of CO by comparing with the National Ambient Air Quality Standard of 4 mg/m^3 (1hour). Potential exposure that exceeds the ambient standard may be of greater concern to public health because they increase the total body burden for CO (USEPA 1999). Receptors were located close to the roadway where pollutant concentrations caused by mobile sources are to be measured. Receptors can exist as part of a grid or as discrete receptors. A receptor was located outside the "mixing zone" of a roadway, which is the total width of the travel lanes of a roadway plus 3 meters (10 feet) on either side. Figure 1 displays the dominant road networks and traffic junction points considered for the air quality prediction at the respective road networks.

Table 1: Road Networks and Traffic Junctions

Index No	Road Networks and Traffic junctions	Latitude	Longitude
R1	**Steel Gate to Chas (National Highway-32) (36 Km)**		
T1	➢ Steel Gate	$23^0$49’19.09”	$86^0$28’58.49”
T2	➢ ISM	$23^0$48’35.09”	$86^0$26’32.57”
T3	➢ Railway Station	$23^0$47’46.19”	$86^0$25’50.29”
T4	➢ Bank More	$23^0$47’19.93”	$86^0$25’11.49”
T5	➢ Karkend	$23^0$45’15.81”	$86^0$23’15.74”
T6	➢ Mohuda More	$23^0$44’57.30”	$86^0$15’01.52”
T7	➢ Chas	$23^0$39’52.97”	$86^0$12’09.50”
R2	**Dhanbad to Sindri (20Km)**		
T4	➢ Bank More	$23^0$47’19.93”	$86^0$25’11.49”
T8	➢ RSP College/Katras More	$23^0$45’09.36”	$86^0$24’44.67”
T9	➢ Jharia	$23^0$44’38.21”	$86^0$24’35.90”
T10	➢ Lodna More	$23^0$43’08.60”	$86^0$24’38.35”
T11	➢ Patherdih	$23^0$40’10.65”	$86^0$26’08.76”
T12	➢ Sindri	$23^0$39’12.14”	$86^0$28’20.88”
R3	**Jharia to Katras (18km)**		
T9	➢ Jharia	$23^0$44’38.21”	$86^0$24’35.90”
T8	➢ Katras More	$23^0$47’52.74”	$86^0$18’07.49”
T5	➢ Karkend	$23^0$45’15.81”	$86^0$23’15.74”
T13	➢ Loyabad	$23^0$48’15.22”	$86^0$21’52.19”
T14	➢ Sijua	$23^0$47’19.93”	$86^0$20’11.35”
T15	➢ Katras	$23^0$47’52.74”	$86^0$18’07.49”
R4	**Sijua to Rajganj (11 Km)**		
T14	➢ Sijua	$23^0$47’19.93”	$86^0$20’11.35”
T16	➢ Tetulmari	$23^0$49’15.22”	$86^0$20’52.19”
T17	➢ Rajganj	$23^0$53’27.11”	$86^0$20’58.54”
R5	**Mohuda More to Rajganj (18Km.)**		
T6	➢ Mohuda More	$23^0$44’57.30”	$86^0$15’01.52”
T18	➢ Kako More	$23^0$51’21.94”;	$86^0$19’06.74”
T19	➢ Tilatanr	$23^0$49’27.11”	$86^0$17’58.54”
T17	➢ Rajganj	$23^0$53’27.11”	$86^0$20’58.54”
R6	**Jharia to Baliapur (11 Km)**		
T9	➢ Jharia	$23^0$44’38.21”	$86^0$24’35.90”
T20	➢ Bandhdih	$23^0$47’27.11”	$86^0$28’58.54”
T21	➢ Baliapur	$23^0$43’30.85”	$86^0$31’27.56”

Model and Pollutant Used

Modelling of air pollution is accomplished with the aid of Gaussian dispersion plume models that accounted for the dispersion characteristics of the pollutants. CALINE 4 model has better performance than other line source models and is widely used to predict near road vehicle emissions (Benson, 1992;

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Loranger *et al.,* 1995; Nagendra and Khare, 2002). Its purpose is to help planners protect public health from the adverse effects of excessive CO exposure. It embeds the concept of mixing zone and uses modified Gaussian plume distributions (Benson, 1984).

The ability of the CALINE 4 model is to predict air quality reliably up to 500 m from the roadway and the special options for modeling air quality near street canyons, intersections and parking facilities bestows a great advantage to the model (Majumdar *et al.,* 2010) with respect to given meteorological condition (e.g., wind speed, wind direction, mixing height, stability class, temperature, background concentrations), source strength (e.g., vehicular density and vehicle emission factor) and road-geometry (e.g., roadway height, receptor locations and heights, number of links, surface roughness, mixing zone width, etc.). The source strength is the amount of pollutant emitted into the air per meter per second (g/m/s), and calculated as the sum of emission factors multiplied by number of vehicles for all classes of vehicles. Total line source strength is the amount of pollutant emitted into the air per second (g/s), and calculated as by multiplying the emission source strength with length of the road.

CALINE 4 uses a series of equivalent finite line sources to represent the road segment. The total road networks is divided into finite number of elements, then each element is modeled as an equivalent finite line source positioned normal to the wind direction and centered at the element midpoint. A local X-Y coordinate system aligned with wind direction and originating at the element midpoint is defined for each element (Majumdar *et al.,* 2008).

The emissions occurring within an element are assumed to be released along finite line sources representing element and it follows the Gaussian dispersion pattern of downwind from the element. Incremental concentration from each link is computed and then summed up to get the total concentration estimate for a definite receptor position. The perpendicular connecting the midpoint of the link and receptor location is known as receptor distance. To estimate the worst case pollutant scenario, worst case wind angle is deployed during the model run. The user defines the proposed roadway geometry, worst-case meteorological parameters, anticipated traffic volumes, and receptor positions.

CO has several advantages as a reference for the estimation of traffic-produced pollutants. It is chemically inert in the atmosphere and it has a low natural background concentration, it is produced by both petrol and diesel engine vehicles and more importantly, it is possible to measure atmospheric CO concentrations continuously and, thus, it provides data for testing the model for short periods when there are considerable fluctuations in the traffic flows and meteorological conditions (Khare and Sharma, 2001; Majumdar *et al.*, 2010).

Performance Evaluation

It is imperative that these dispersion be properly evaluated with the observational data before their predictions can be used with confidence, because the model result often influence decisions that have large public health and economic consequences. For statistical evaluation, the predictions are evaluated against some reference states, i.e., observations which are directly measured using instruments.

Various statistical methods like- Index of agreement (d), Fractional Bias (FB), Normalized Mean Square Error (NMSE), Geometric Mean Bias (MG), and the fraction of predictions within a factor of two of observations was recommended by Hanna *et al.,* (1993) have been used for validation. These models were used for simulating the short-term pollution levels due to mining operations and its application in Indian context.

Model bias is also an important statistical analysis to evaluate whether the model is under-predicting or over-predicting as per negative and positive values. Perfect agreement between model predictions and observations would give bias=0. So, if a confidence interval included 0, a model's performance would be deemed a success with respect to this criterion. In other words it is the mean error, which is defined as the observed value of concentration less than the predicted value. It is given by as follows:

$$MB = \overline{(C_O - C_P)}$$

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The normalized mean square error is a fundamental statistical performance parameter. Since it gives information on the actual value of the error produced by the model, it emphasizes the scatter in the entire data set. NMSE is articulated as follows:

$$NMSE = \frac{\overline{(C_O - C_P)^2}}{\overline{C_O} \times \overline{C_P}}$$

The correlation coefficient can be described proportional change with regard to the means of two quantities in question, but cannot distinguish the type or magnitude of possible covariance. The correlation (r) close to 1 indicates perfect correlation between the observed and predicted values which is a sign of good model performance. The coefficient of correlation is given by:

$$r = \frac{\overline{(C_O - \overline{C_P}) \times (C_P - \overline{C_P})}}{\sigma_{CP} \times \sigma_{CO}}$$

The fractional bias (FB) is a non-linear operator that is used to represent the relative difference between models predicted value and observed value in a bounded range (-2 to2) and has an ideal value of zero for an ideal model

$$FB = \frac{2(\overline{C_O} - \overline{C_P})}{(\overline{C_O} + \overline{C_P})}$$

Geometrical mean bias is measures of mean relative bias and indicates only systematic errors. It represents as follows:

$$MG = \exp\left(\overline{lnC_o} - \overline{lnC_p}\right)$$

Where,
C_p: Predicted values,
C_o: Observed values for all the cases,
Over bar: average over the data set.
For an ideal prediction, the value of MG has to be 1.0 and the values of FB and NMSE=0.0. The linear measures of FB and NMSE are overly influenced by infrequent occurring of high observed or predicted concentrations, whereas the logarithmic measure MG provide a more balanced treatment of extreme high or low values. Therefore, for a dataset where both predicted and observed concentrations vary by many orders of magnitude, MG is more appropriate. The performance of the model would be acceptable if NMSE ≤ 0.5 $-0.7<FB<0.7$.

RESULTS AND DISCUSSION

Field motor vehicle counts were continuously monitored for different categories of vehicles (i.e. heavy duty, light duty petrol and diesel, etc.) for each road network. Based on this database, average daily vehicular movement on the different road networks of the study area were evaluated as shown in Table 2 at every strategic locations CO concentration were monitored as shown in Table 3.

Table 2: Average Vehicular Count on different Road Networks

S. No.	Road Networks	Heavy vehicles		Light vehicles (Cars/Taxis, etc)	Three wheeler (Tempo, Auto-Rickshaw)	Two wheeler (Motor cycle, Scooter, moped)	Total vehicls
		(Bus, Trekkers)	Trucks/ Tractors/ Tailors/ Goods vehicles				
1	NH-32	257	288	1374	1078	3510	6507
2	Dhanbad To Sindri	126	252	2496	2589	4791	10254
3	Jharia to Katras	133	213	2693	2829	5320	11188
4	Sijua To Rajganj	136	260	2516	2805	5590	11307
5	Mohuda More To Rajganj	390	464	954	421	3768	5997
6	Jharia To Baliapur	135	213	2302	2999	5400	11049

Table 3: Average Monitored CO Concentration at Selected Strategic Locations

Traffic Junction points	Code	Average Monitored CO in ppm		
		9.00 to10.00 hours	12.00 to 13.00 hours	17.00 to 18.00 hours
Steel gate	RC1	0.90	0.92	0.86
ISM-Main gate	RC2	0.80	0.88	0.78
Railway Station	RC3	1.34	0.98	0.88
Bank More	RC4	1.50	1.43	1.30
Karkend	RC5	0.87	0.84	0.78
Mohuda	RC6	1.12	1.10	1.00
Chas	RC7	1.09	0.96	0.92
RSP college	RC8	0.70	0.67	0.60
Jharia	RC9	0.94	0.90	0.85
Patherdih	RC10	0.87	0.85	0.78
Sindri	RC11	0.34	0.30	0.24
Loyabad	RC12	0.55	0.54	0.50
Sijua	RC13	0.65	0.55	0.49
Katras	RC14	0.69	0.65	0.60
Tetulmari	RC15	0.67	0.61	0.55
Kako More	RC16	0.58	0.56	0.51
Tilatanr	RC17	0.60	0.58	0.53
Rajganj	RC18	0.56	0.53	0.48
Bandhdih	RC19	0.49	0.47	0.43
Baliapur	RC20	0.53	0.50	0.45

In this connection deterioration and emission factors for different categories of vehicles was collected from CPCB Publication (Transport Fuel Quality for Year, 2005) as shown in Table 4. Deterioration factor and emission factor for different categories of vehicles were calculated.

Table 4: Deterioration and Emission factors for different Categories of Vehicles

	Category of Vehicles				
	Heavy vehicles (Bus, Goods vehicle)	Trucks/Tractors	Light vehicles (cars/taxis, etc)	Three wheeler (Tempo, Auto-Rickshaw)	Two wheeler (Motor cycle, Scooter, moped)
Deterioration factor	1.18	1.33	1.14	1.70	1.30
Emission factor (g/km)	3.6	3.6	0.9	4.3	2.2

Source: Transport Fuel Quality for Year 2005, CPCB

Pollution load of different category of vehicles on each road network was determined using equation 1.0. The total number of vehicles for each category was used to estimate emission as daily average. That time period was selected because the minimum averaging period for the dispersion modeling is 24 hours for particulate matter.

$$\text{Pollution load}=T_n \text{ x } X_i \text{ x } T_{(0\text{-}5)}\text{x}L\text{x}R_1 \ldots\ldots\ldots \text{(Equation 1.0)}$$

Where, X_i – Pollutant parameter
T_n – Number of vehicles during 24 hours
$T_{(0\text{-}5)}$ - Deterioration factor in five years
L – Road length in km
R1 – Factor representing intermediate road link
Accordingly the pollution load of CO at six different road networks was evaluated as shown in Table 5.

Table 5: Vehicular Pollution Load at different Road Networks (g/m/s)

S. No	Road networks	CO(g/m/s)
1	NH-32(36km)	3.35E-01
2	Dhanbad to Sindri (20km)	2.55E-01
3	Jharia to Katras(18km)	1.99E-01
4	Sijua to Rajganj (11km)	7.10E-02
5	Mohuda More to Rajganj(18km)	5.79E-02
6	Jharia to Baliapur(11km)	7.50E-02

Model output (CALINE-4) as shown in Table 6 revealed maximum concentrations of 1.70 ,1.56, 1.46 ppm at Bank More (T4) and 1.54, 1.48 and 1.40 ppm at Railway Station (T3) junction followed by 1.43, 1.31 and 1.37 ppm at Mohuda (T6) during three peak traffic situations (9.00 to 10.00 hours, 12.00 to 13.00 hours and 17.00 to 18.00 hours, respectively).

Table 6: Predicted CO Concentration (CALINE4) at Selected Strategic Locations

Traffic Junction points	**Code**	**Average Predicted CO in ppm**		
		9.00-10.00 hours	**12.00 to13.00 hours**	**17.00 to 18.00 hours**
Steel Gate	RC1	1.12	1.10	1.00
ISM-Main Gate	RC2	0.90	0.98	0.88
Railway Station	RC3	1.54	1.48	1.40
Bank More	RC4	1.70	1.56	1.46
Karkend	RC5	1.09	0.92	1.00
Mohuda	RC6	1.43	1.31	1.37
Chas	RC7	1.34	1.23	1.10
RSP college	RC8	0.85	0.73	0.78
Jharia	RC9	1.10	1.04	1.05
Patherdih	RC10	0.98	0.92	0.90
Sindri	RC11	0.54	0.48	0.50
Loyabad	RC12	0.78	0.67	0.73
Sijua	RC13	0.87	0.76	0.80
Katras	RC14	0.89	0.71	0.83
Tetulmari	RC15	0.77	0.67	0.68
Kako More	RC16	0.76	0.64	0.71
Tilatanr	RC17	0.81	0.76	0.73
Rajganj	RC18	0.76	0.64	0.72
Bandhdih	RC19	0.64	0.54	0.60
Baliapur	RC20	0.70	0.61	0.67

Model Performance

Necessary statistical analysis was also carried out to assess the performance of the models based on a set measured and predicted CO concentration data as shown in Table 7.

Table 7: Statistical Evaluation of CALINE-4 model

Statistical analysis	**CALINE-4**
Average observed concentration (ppm)	0.735
Average predicted concentration (ppm)	0.92
Correlation coefficient	0.91

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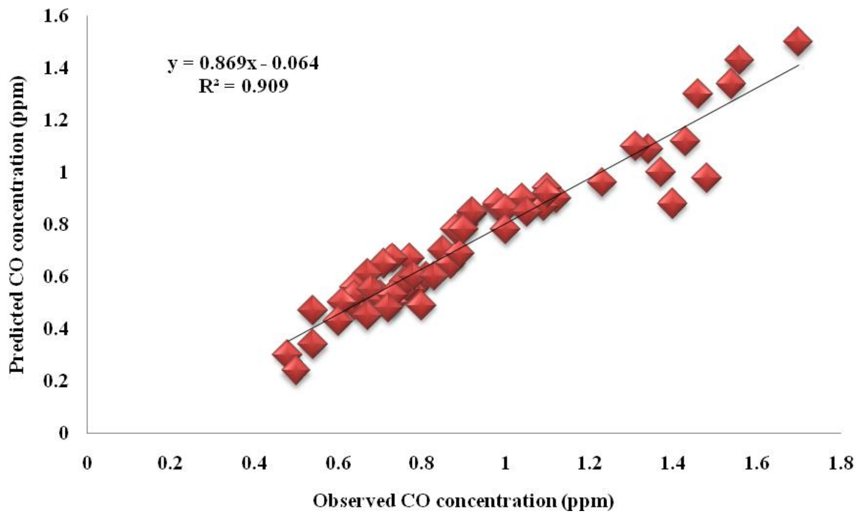

Figure 2:Correlation Analysis between Observed and Predicted CO by CALINE-4

It is evident that CALINE 4 model is over predicting whereas AERMOD line source model is under predicting the concentration of CO pollutant. However, higher value of ‘r’ in case of CALINE4 indicates that model is more appropriate in application of predicting CO dispersion. Scatter plots of observed and predicted concentration (Figure 2) along with regression coefficients of the two models have found a good agreement of above statement.

Conclusion

This paper is devoted to evaluate emission levels of CO due to vehicular exhaust at various traffic junction points in the study area. These data base were used in CALINE 4 model (line source) for evaluating its suitability for line source modeling.

With respect to one hour modeling of CO for vehicular traffic, CALINE 4 indicates more appropriate. The problem of vehicular pollution mainly arises due to emissions from plying of vehicles at various road networks. Thus, air quality management is a growing concern for the industrial region like study area. As such, it is quite necessary to have regular assessment and prediction of air quality. This will help in providing database to prevent and minimize the deterioration of air quality in the study area.

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