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## Development of Relationship between Various Performance Measures with Focus on Sustainability Assessment

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**ABSTRACT:** In the past years, there has been a massive increase in the population and economic behaviour of India which leads to various serious traffic problems such as accidents, traffic congestion, delay in travel time, increase in air pollution, etc. Adding to this, the lack of public transportation facilities has led an increase in the private vehicle ownership levels. In this research, the sustainability assessment of Nagpur MRTS is considered. However it can be said that the traffic conditions have a dependency on sustainability assessment. The aim of the project is to check the dependency and to develop the relationship between the traffic parameters with sustainability assessment parameters. The present traffic parameters are considered and data collection for the same is being conducted. The traffic parameters considered are speed, volume, density and headway. The links connecting one metro station to the other are selected for the study area.

**KEYWORDS:-** sustainability assessment, speed, volume, density, headway.

### I. INTRODUCTION

Many major cities are facing serious problems related to traffic congestion, road accidents, increased travel time, delays, etc. These problems are more serious in the developing countries. The lack of public transportation facilities have led an increase in the private transportation system, which ultimately gives rise to traffic congestion. It is a condition on road network because of the increase in the number of vehicles on road, and is identified by lower speeds, elongated travel times, and increased vehicle queuing. When traffic demand is sufficient that the interface between vehicles lowers the speed in the road network, this results in traffic jam. Traffic congestion leads to emit a large quantity of automobile pollutants in the environment and respondents have been suffering from various chronic diseases.

It negatively impacts people which may affect productivity at work and relationships. Roads with traffic jam can be seen as an example of misfortune for the riders. This necessitates adopting strategy to decrease the private transportation system and support the public transportation system. Execution of Mass Rapid Transit System (MRTS) becomes more efficient as it provides vast benefits like lowering the pollution levels, saving travel time, reduction in the rate of accidents, traffic congestion reduction. But sustainability assessment of transportation system is of great importance as it gives a clear idea of the project. However it can be said that traffic conditions have a dependency on the sustainability assessment. In this study, the aim is to develop a relationship between the performance measures of the transit system i.e traffic characteristics and the sustainability assessment parameters which can elicit understanding and at the same time can relate the conditions of traffic with sustainability assessment. Therefore, this relationship supports us understand the real-time correlation between traffic characteristics and sustainability assessment.

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In India, traffic jam is apparently on the rise. This has an adverse effect on work-rate, air pollution, loss of fuels, well-being, and quality of life. In the developing countries, traffic jams has been identified as an economic as well as a social restraint, and detail survey on economic feature of congestion have been organized. Such surveys have been victorious in igniting innumerable policies consultation, and have generated interest in framing India developed. Traffic jams in cities is going to increase dashingly, with number of negative indications. Nagpur is a city in the state of Maharashtra and is well known for highly dense population, mixed traffic flow, wide network of highways, highly polluted and of broadly dispersed pattern. These factors are responsible for time consumption of people and pollution in the city results into the impact on health of people. Thus it forces to put forward the need of sustainable transportation concept in front of society. The automobile dependency creates another set of problem in terms of high-energy consumption, and with depleting fossil fuels resources. This makes us realize the need of development in sustainability. Sustainable transportation refers to any means of transport which reduces the travelling time with low impact on environment and thus on human health without compromising capacity of future need. It provides easy access to the people to any corner of city in a safe and environment friendly mode of transport. Transportation sustainability is measured by usefulness and regulation of transportation system. Different strategies includes planning of transportation properly, integrated land use, use of clean fuels, pricing policies, etc.



The Nagpur Metro is aimed to increase the public transportation system with the decrease in the usage of private transportation system and to benefit the people using transportation system. The Nagpur metro will not just transport people, it will offer Housing, eco- parks and urban forests, shopping arcades and office spaces. In fact, Nagpur metro is not just a ‘transport system’ it is creation of a new ‘Mini Nagpur’ where people can live, go to work, go shopping, visit friends etc. without the need of owning their own vehicles. All this will be done travelling in metros! This is because the two metro depots at Hingna and Khapri will have residential complex’ built above the depots. Each complex will

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have housing units for 5000 families. On the other hand, stations at zero milestone, Sitabuldi, etc will be multi storeyed offering space for office complex and other commercial purpose. This is a model of TOD – Transit oriented Development – along with Urban planning, happening for the very first time in Nagpur!

## Objectives and Scope of Project

1. To identify the traffic parameters that can be related with sustainability assessment.
2. Data collection for the defined parameters.
3. To analyze the traffic parameters viz. speed, volume, density, headway.
4. To check the dependency of sustainability assessment on these parameters.
5. To assess the dependency of sustainability assessment parameters.

## Purpose of Study

The purpose of the research work to attain the above stated objectives are stated below:-

1. To elicit a better understanding of sustainability assessment.
2. To relate the sustainability assessment tool with the present traffic conditions.
3. To relate the traffic parameters with sustainability assessment parameters.

## II. LITERATURE REVIEW

This is an interpretative report of the information related to the title. It offers explanation, overview and survey of journal papers referred for the research work. It includes authenticate findings, as well as conceptual and strategic explanation about the title.

### Previous Research Study

Tara Ramani *et al.* (2011) introduced a performance measurement established scheme and assessment approach for sustainable transportation. This research focussed on the performance measures like safety, congestion and environment to address the objectives of sustainable transportation. The MAUT (Multi Attribute Utility Theory) method was applied to evaluate and generalize the preferred performance measures and determine sustainability index merits for the present as well as for future traffic conditions. Amadapuram Mohan Rao *et al.* (2012) identified that traffic congestion in perception as well as in actuality effects the motion of people. Traffic congestion leads to wastage of time, energy and causes pollution. The factors affecting traffic congestion were broadly classified into micro as well as macro-level factors which relates to the gross demand of road usage. A descriptive review was carried out on the basis of the quantitative characteristics specifically speed, travel time, delay time, traffic flow and level of service.

Raed Alsahi *et al.* (2015) proposed a methodology to understand the relationship between the traffic parameters and traffic safety. The method can be used for evaluating traffic safety at the macroscopic scale. It contains a total of eighteen equations linking accidents and traffic parameters viz. speed, density and flow. The results concluded that change of speed and density has more effect on safety than change of flow. Ameena Salim *et al.* (2010) attempted the estimation of average space headway under heterogeneous traffic condition. Space headway is an important traffic parameter and have direct links with the traffic density. But it was found that, it is difficult to measure the space headway from field and hence is estimated from the location based parameters like time headway and average speed. The data calculation included the flow of vehicles at entry and exit points.

P. C. Bueno *et al.* (2011) reviewed the subsisting tools and technologies used for sustainability assessment of the transportation infrastructure estimates. It is found that not any of the subsisting practices and tools discussed involved the imperative requirements to be suitable to satisfy the sustainability of the transportation projects. However, most of them put forward some merit for sustainability assessment, but not any of them could be used to accomplish a comprehensive assessment. Sourabh Ladhi *et al.* (2018) compared the present traffic situation of Nagpur city considering parameters like queue length, level of service, delay, emission and fuel consumption with the futuristic traffic conditions after the implementation of metro rail. With the help of traffic volume count survey, analysis and

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comparison of above parameters were done and observed that implementation of metro will reduce the queue length, delay time, fuel consumption and vehicular emissions.

## III. METHODOLOGY

This chapter discusses the overall methodology that is adopted in order to achieve the objectives of the project. The flow chart shown below in fig 3.1 shows the step by step process for the research work.



Fig 1: Flow Chart for the Project

### Study Area

Different types of surveys were conducted by the DMRC, and as a result the metro alignment was finalized. These included repeated inspections of the transport network, crossings, commuter traffic flow and traffic jam. The metro alignment is designed such that it connects important areas of the city. A total of 6 links are considered i.e. 3 links on the North-South corridor and 3 links on the East-West corridor as the study area. The 6 links considered for the traffic data collection and analysis are stated below

**Table 1: Alignment of Nagpur Metro Rail**

North-South Corridor:-

- Link 1:- Automotive Square to Teka Naka Square
- Link 2:- Teka Naka Square to Indora Square
- Link 3:- Indora Square to Kadvi Square

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Link 4:- Vaishno Devi Square to Ambedkar Square  
Link 5:- Ambedkar Square to Telephone Exchange Square  
Link 6:- Telephone Exchange Square

Traffic data was collected on all the selected links by using digital video camera. The recording was done in the mid-block section of the road on all the links. The camera covered a total distance of 35m of the road with a specific height that no vehicles get covered by other vehicles in the traffic stream. The survey was conducted during the evening peak hour i.e. 6 pm to 7 pm. After that traffic parameters viz. Speed, volume, density, headway were calculated accordingly.

Alignment	Route Length			Number of Stations	
	Elevated (km)	At Grade (km)	Total (km)	Elevated	At Grade
North-South Line : Automotive Square to Khapri	15.058	4.60	19.658	15	2
East-West Line : Prajapati Nagar to Lokmanya Nagar	18.557	0	18.557	19	0

## Speed

Speed is an influential traffic characteristic as it correlates with safety, time, relief, convenience and economics. The speed distribution of a traffic stream can be determined with the help of spot speed studies. The videographic method can be used to successfully complete the spot speed study using a sample size taken over a short period of time. The study length taken should be good enough to make speed calculations straight forward and less confusing. Also, while selecting the location and layout, care must be taken that the camera is placed at a desired height so that no vehicle gets covered with any other vehicles in the traffic stream. Two reference points should be considered to aid in collecting the elapsed time taken by the vehicle to travel the study area.

Spot Speed is calculated by:-

$$Speed = \frac{Distance}{Time}$$

$$V_s = \frac{D}{T}$$

Where,  $V_s$  = spot speed in (m/s)

D = study length in (m)

T = time taken by the vehicle to cover study length in (s)

## Volume

Traffic volume surveys are carried out to know the statistic, motions and classification of the automobiles on the road. The length of sample size is based on the type of count to extract and the purposeful usage of the data that is been noted. Traffic volume is described as the no. of vehicles passing a particular point on the road. Its unit is vehicles/hour

## Density

Density of traffic is described as the no. of vehicles engrossed in a given stretch and its unit is vehicles per kilometre. The data collected of the study area of length 'x' on the road, the number of vehicles can be counted i.e. ' $n_x$ ' in 1 lane at that point of time then the density 'k' can be calculated as,



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$$k = \frac{n_x}{x}$$

It is the number of vehicles between both the reference point divided by the distance between them.

## Time Headway

Time headway is one of the important indicators of traffic safety. Time headway is described as the elapsed time between the rear end of the foremost vehicle passing a particular point on the road and the rear end of the successive vehicle passing the same point. In general, headway is the reciprocal of volume. The average headway is defined as the ratio of volume and time. Therefore the average headway for one hour can be computed as follows:-

$$\text{Average Headway} = \frac{\text{Total Volume}}{3600}$$

The obtained data captured from videography is run in VLC media player and analysis is done by manual method. By observing the flow of traffic, vehicles can be categorized into 6 main type of vehicles i.e motorcycle, auto, car, Light Commercial Vehicle (LCV), bus and truck.

Table 2: Traffic Volume & Vehicular Composition

Link	Motor Cycle	Auto	Car	LCV	Bus	Truck	Total
Link 1	1054	163	227	55	25	8	1532
Link 2	1278	246	319	17	16	6	1882
Link 3	894	128	204	34	16	6	1282
Link 4	1412	93	229	49	2	15	1800
Link 5	1820	120	285	85	3	17	2330
Link 6	949	93	265	14	3	10	1334

The volume of the traffic was counted manually by running the video. It was observed that the proportion of motorcycles is much greater than any other vehicular composition. Since the study area lies in the inner city, the contribution of heavy vehicles is less.

Table 3: Traffic Speed, density and headway data

Link	Speed(V) (kmph)	Density(k) (veh/km/ln)	Average Headway
Link 1	35.68	46.42	0.426
Link 2	26.23	53.77	0.523
Link 3	28.97	36.63	0.371
Link 4	25.36	60.00	0.5
Link 5	22.66	93.2	0.647
Link 6	36.74	74.11	0.287

Traffic characteristics like speed, density and headway were obtained by using the Microsoft Excel as a tool for calculation. It was found easy to calculate the speed of the vehicles as well as density and average headway of the particular section.

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## Sustainability Assessment

It is a method carried out for assisting the decision-making policy in a wide environmental, economical and social factors and therefore surpass a purely technological estimation. As far as sustainability assessment of transportation system is concerned, the strategic goals include reduction in congestion, safety enhancement, economic expansion opportunities, air quality improvement and value enhancement of transportation assets. On the basis of these strategic goals, their performance measures are given below.

### 1. Reduction in congestion

#### 1. Travel Time Index

The time required to cover the distance due to congestion is known as Travel Time Index. It is the proportion of peak period travel time to off peak period travel time along the stretch.

#### 2. Program Time Index

It considers the extra time required cover the distance with the current traffic than the time required to travel the distance with free flow speed. Moreover, it reflects the extents to which 95<sup>th</sup> percentile of travel time exceeds the mean travel time for the stretch under consideration.

### 2. Safety enhancement

#### 1. Annual Severe Crash

It considers the crashes occurring on the link in a year. For the purpose, the prediction model is used and the method given in the Interim Roadway Safety Design Workbook is adopted. By using the prediction model, the fatal crashes resulting in injuries defines the frequency on annual basis.

#### 2. Percentage lane mile under surveillance

This is an indication that estimates the presence of Intelligent Transportation System provisions for traffic monitoring and response facilities to cover the section operated by a Traffic Monitoring Center.

### 3. Economic expansion opportunities

#### 1. Land Use Balance

It indicates the land use pattern of the area on both the sides of the link. The land categorizes in three parts i.e. residential, commercial and public.

#### 2. Truck Throughput Efficiency

This indicates the truck volume along the selected section in combination with the travel speeds. It enhances the freight throughput without affecting the system performance.

### 4. Air quality improvement

#### 1. Daily NO<sub>x</sub>, CO and VOC emissions.

It represents the emission of Carbon Monoxide, Nitrogen Oxide and Volatile Organic Compound by the vehicles.

#### 2. Daily CO<sub>2</sub> emissions

It represents the emissions of Carbon-dioxide in the environment by the vehicles along the stretch.

### 5. Value enhancement of transportation assets

#### 1. Average Pavement Condition Score

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Table 4: Results of Sustainability Assessment parameters

	TTI	PTI	Annual Severe Crashes Per Mile	Lane km under TMC	Truck Throughput Efficiency	Pavement Condition Score
Link 1	2.12	2.02	11.41	50	60011.95	53
Link 2	2.33	2.22	11.29	40	-	55
Link 3	2.50	2.38	10.12	70	-	55
Link 4	2.80	2.66	11.14	60	-	60
Link 5	3.18	3.02	9.17	80	-	65
Link 6	3.50	3.33	12.90	85	-	65

The end results of travel time index, program time index, annual severe crashes per mile, lane km under TMC, truck throughput efficiency and pavement condition score are given above. The tool which is used for sustainability assessment is MAUT (Multi Attribute Utility Theory) method.

Table 5: Results of Sustainability Assessment parameters

	Capacity Addition Within ROW	CO2 Emissions	Land-Use Balance	VOC & CO Combined
Link 1	0.25	3036410	0.924	8800.92
Link 2	0.25	2622880	1.077	7602.32
Link 3	0.5	2563990	0.973	7431.63
Link 4	0.5	2496650	0.628	7236.44
Link 5	0.25	2962570	0.282	8586.90
Link 6	0.25	3303430	0.193	9574.86

The end results of the remaining parameters like capacity addition within ROW, CO2 emissions, land-use balance, VOC and CO combined are given above. With the help of these results the dependency can be checked on traffic parameters.

## IV. RESULT

The study plays an important role in understanding the relationship between sustainability assessment and traffic parameters. In this study, traffic parameters were analyzed simultaneously. The results were divided into four main sections, each of which represented a different traffic parameter (speed, volume, density and headway) and its relationship with sustainability assessment.

### Speed and sustainability assessment.

In this section, the relationship between speed and sustainability assessment was investigated. The computation of the value of the coefficient of determination ( $R^2$ ) was completed for the sustainability assessment parameters. In figure 6.1 we can see the regressions for each of the sustainability assessment parameters with speed.



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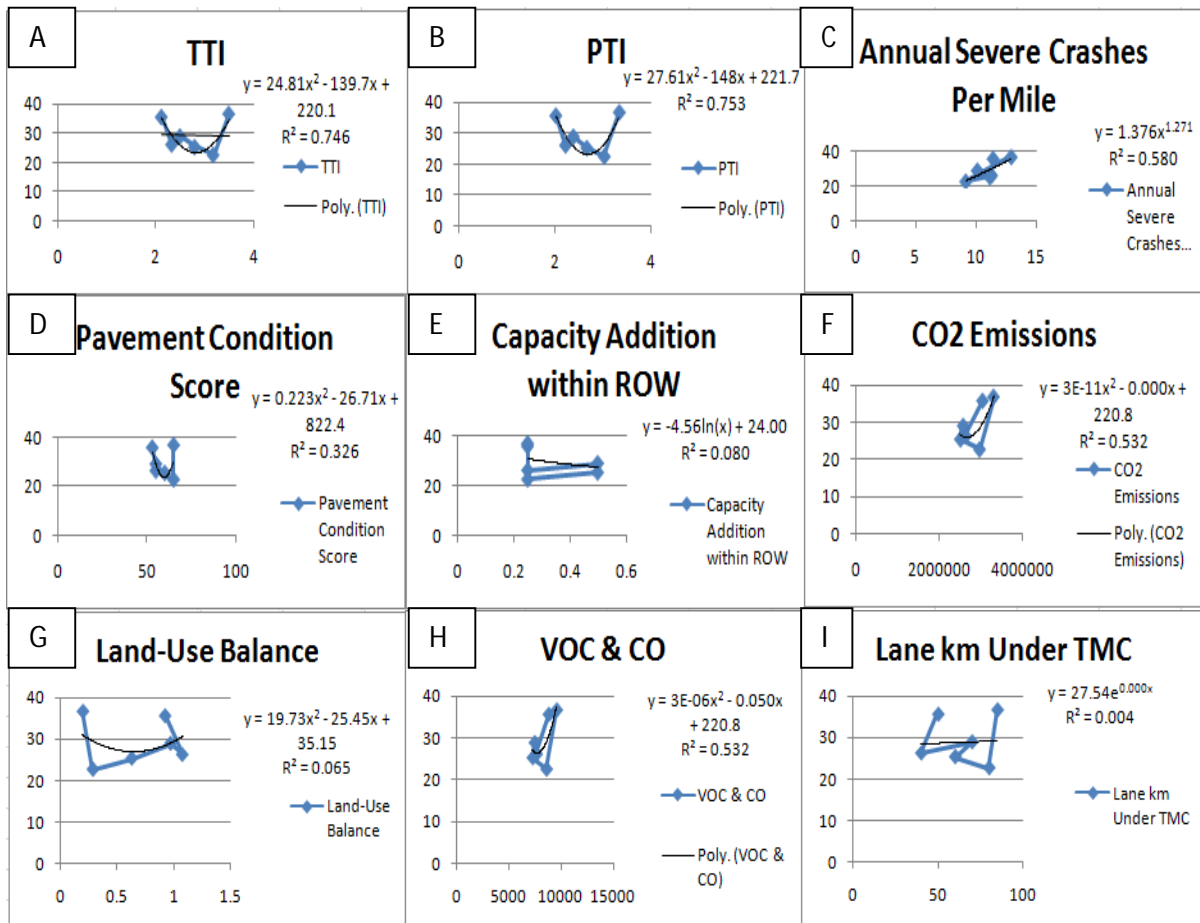


Fig 3: Graphical representation of sustainability assessment versus speed

	A	B	C	D	E	F	G	H	I
$R^2$	0.746	0.753	0.580	0.326	0.080	0.532	0.065	0.532	0.004

Table 6: Coefficient of determination ( $R^2$ ) Values for sustainability assessment versus speed

From table 6, we can see that the value of  $R^2$  was very important for the figures A, B, C, H while in the figures of D, E, F, G and I were less important. This depicts that Travel Time Index, Program Time Index, Annual Severe Crashes Per mile and VOC & CO emissions are more considerable to have dependency on speed than other parameters of sustainability assessment.

## Volume and sustainability assessment

In this section, the relationship between volume and sustainability assessment was investigated. The computation of the value of the coefficient of determination ( $R^2$ ) was completed for the sustainability assessment parameters. In figure 6.2 we can see the regressions for each of the sustainability assessment parameters with volume.

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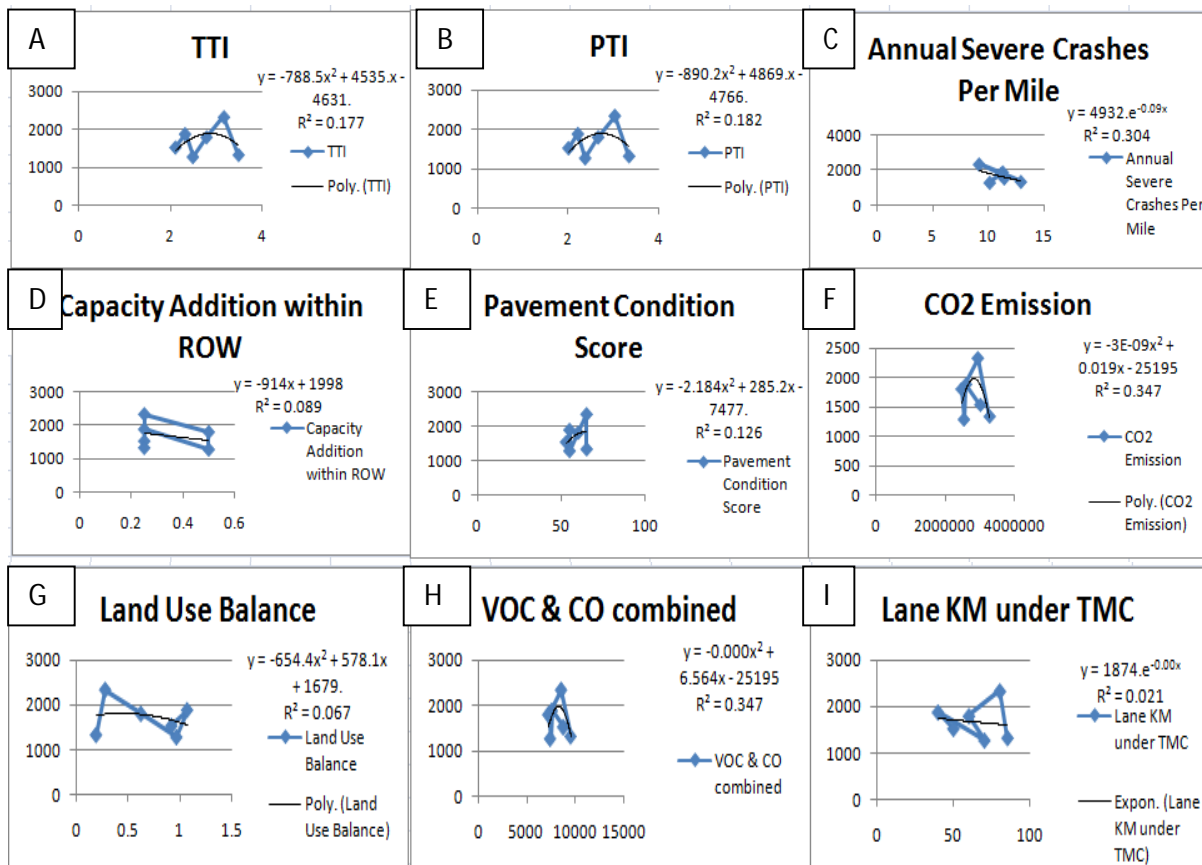


Fig 4: Graphical representation of sustainability assessment versus volume

	A	B	C	D	E	F	G	H	I
$R^2$	0.177	0.182	0.304	0.089	0.126	0.347	0.067	0.347	0.021

Table 7: Coefficient of determination ( $R^2$ ) Values for sustainability assessment versus volume

From table 7, we can see that the value of  $R^2$  was very less important for all the stated parameters as it came to be less than 0.5. With this, it can be stated that the dependency of sustainability assessment is very less considerable on the volume.

## Density and sustainability assessment

In this section, the relationship between density and sustainability assessment was investigated. The computation of the value of the coefficient of determination ( $R^2$ ) was completed for the sustainability assessment parameters. In figure 6.3 we can see the regressions for each of the sustainability assessment parameters with density.

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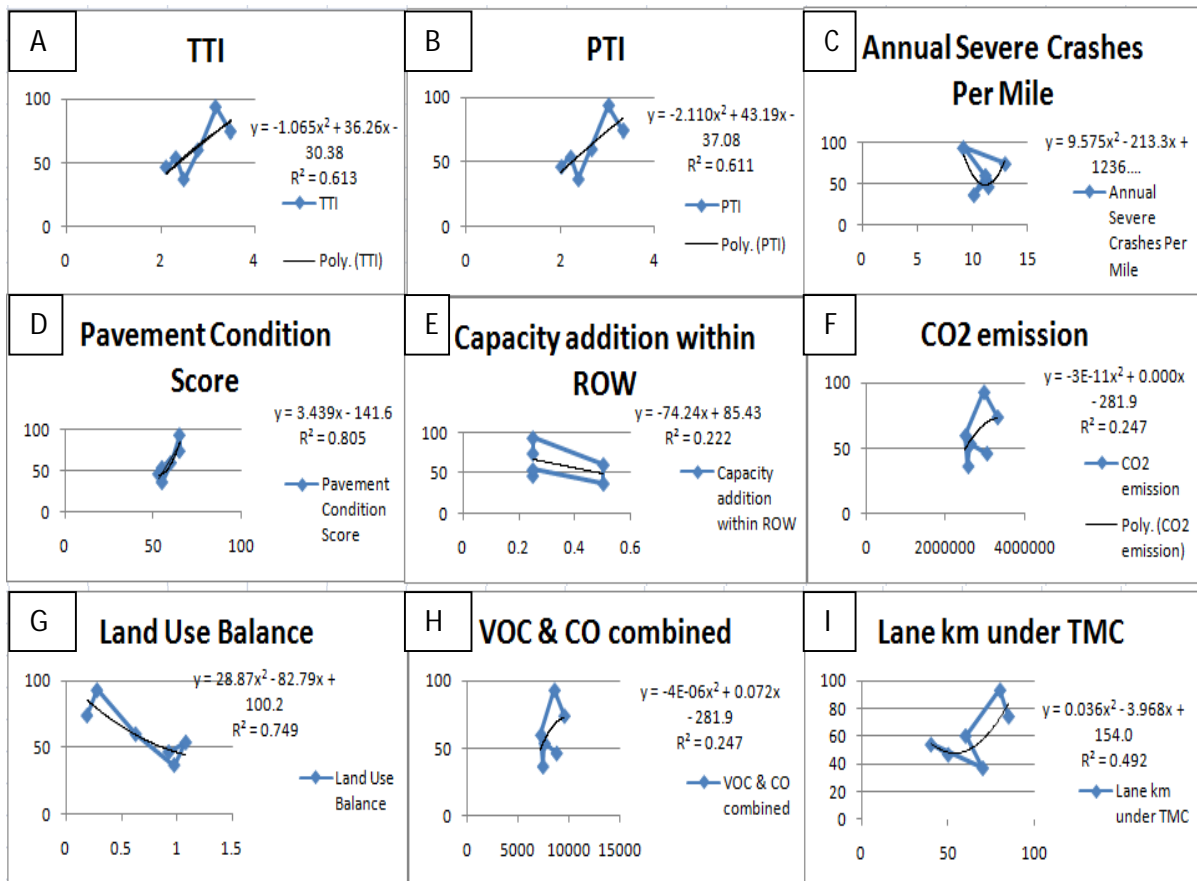


Fig 5: Graphical representation of sustainability assessment versus density

	A	B	C	D	E	F	G	H	I
$R^2$	0.613	0.611	0.026	0.805	0.222	0.247	0.749	0.247	0.492

Table 8: Coefficient of determination ( $R^2$ ) Values for sustainability assessment versus density

From table 7, we can see that the value of  $R^2$  was very important for the figures A, B, D and G while in the figures of C, E, F, H and I were less important. This depicts that Travel Time Index, Program Time Index, Pavement Condition Score and Land-Use Balance are more considerable to have dependency on speed than other parameters of sustainability assessment.

## Headway and sustainability assessment

In this section, the relationship between headway and sustainability assessment was investigated. The computation of the value of the coefficient of determination ( $R^2$ ) was completed for the sustainability assessment parameters. In figure 6.4 we can see the regressions for each of the sustainability assessment parameters with headway.

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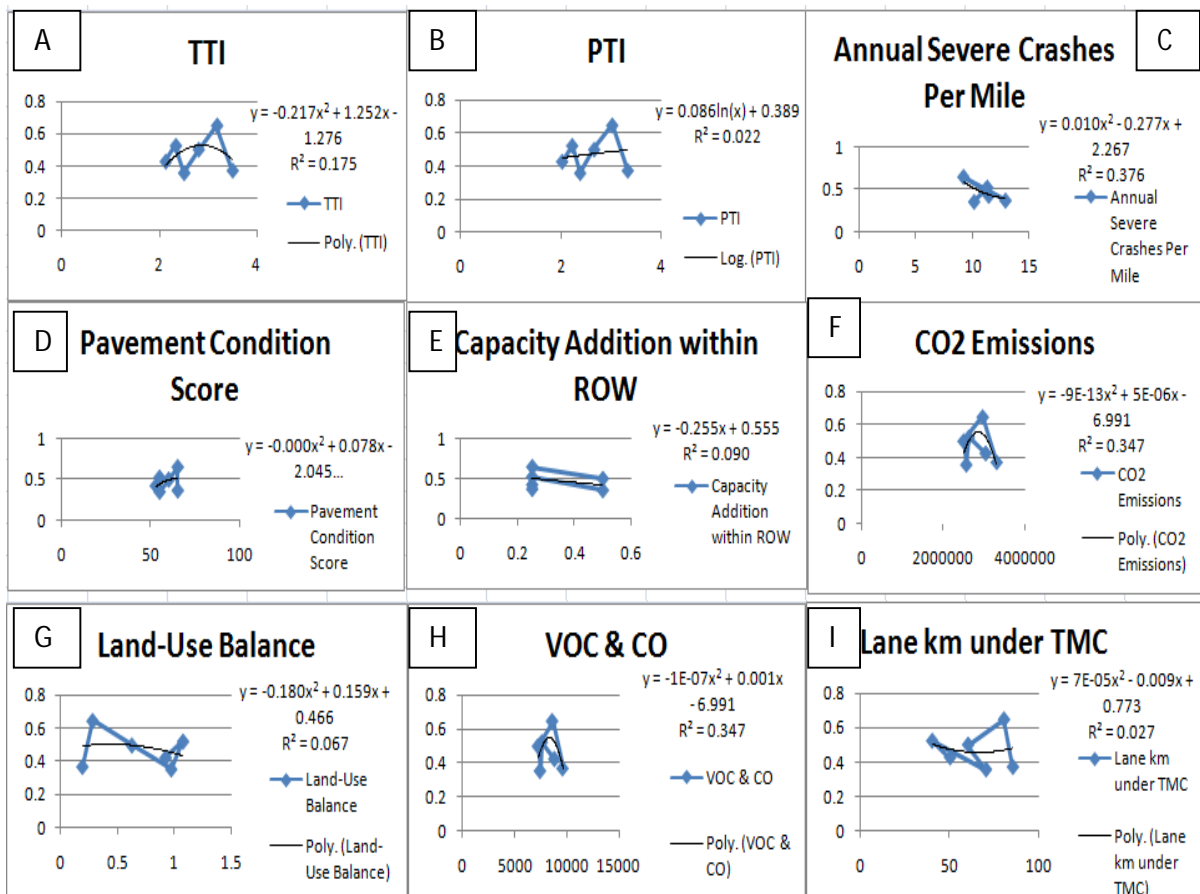


Fig 6: Graphical representation of sustainability assessment versus headway

	A	B	C	D	E	F	G	H	I
$R^2$	0.175	0.022	0.376	0.126	0.090	0.347	0.067	0.347	0.027

Table 9: Coefficient of determination ( $R^2$ ) Values for sustainability assessment versus headway

From table 9, we can see that the value of  $R^2$  was very less important for all the stated parameters as it came to be less than 0.5. With this, it can be stated that the dependency of sustainability assessment is very less considerable on the headway.

## V. CONCLUSION

In this paper, we tried to develop relationship between sustainability assessment and present traffic conditions. The proposed work contains twenty six equations linking sustainability assessment and traffic parameters. We found that while some equations had a strong relationship, others have a weak relationship. The future work will be using the relationship to develop algorithms for sustainability assessment. But, before that can happen, more real-time and quantitative data must be collected and analyzed.

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## VI. FUTURE SCOPE

The above results and conclusion are showing the relationship between sustainability assessment and traffic parameters. Also, some of the parameters have a strong dependency on sustainability assessment. In this paper, major 4 traffic parameters were taken into consideration i.e. speed, volume, density and headway. But there are more traffic parameters that can be considered and their dependency can be checked and relationship between them can be developed.

The following points can be considered for future scope:-

- The parameters considered can be analysed with other sustainability assessment tools except MAUT.
- More traffic parameters can be considered and tried to develop the relationship.
- Implementation of relationship can be done while designing algorithms for sustainability assessment.
- The sample size of the study area can be increased along with the parameters for more detailed study.

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