Estimating Traffic Density: Trends and the Impact of BRT Construction on Traffic Junctions of Karachi using Geospatial Techniques

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Abstract—Everyone must commute on a daily basis to work, get educated, buy necessities, seek entertainment or visit friends and family. Thus, transport infrastructure has become an integral or probably the most important aspect of urban design. Major cities of the world have a mass transit system or even multimodal transport system to cater for the transportation needs of their citizens. Karachi, a mega city of approximately 23 million residents lacks a properly coordinated and well scheduled transportation mechanism. Therefore, its residents primarily rely on their own means to fulfill their commuting needs resulting in heavy traffic and very significant time delays on its roads. These time delays and rush hour frustrations in turn have a negative impact on the overall productivity and psychological and social well-being of the populace. The government has in recent years taken up this matter seriously and begun construction of Bus Rapid Transit (BRT) systems along various major traffic corridors of Karachi. The purpose of this thesis was to study the change of traffic behavior in recent years, traffic density variations and the impact on transportation road might have along its corridors using geospatial techniques. The results of this study showed that daily average passenger commutes experienced an increase of approximately 58.4% from 2012 to 2017 and that major mode of transportation shifted from public transit vehicles to private ones especially motorcycles resulting in unfavorable occupancy to Passenger Car Unit (PCU) ratio. This in turn has adversely affected the traffic density of the city. This congestion can only see some relief when the BRT becomes operational.

Index Terms—Estimation, Traffic Density, Bus Rapid Transit (BRT) Construction, Geospatial Techniques, Traffic Junctions.

I. INTRODUCTION

Currently, large cities depend, in particular, on the transportation system and the congestion of traffic has bad impact on economic survival and environmental social sustainability. Over the years, the infrastructures of such busy avenues have reached a certain degree of stagnation, especially in the urbanized area of Karachi. The number of new vehicles entering the road is increasing. Each year, new cars are heavily registered, but there is no culture that can discard old antique cars in Pakistan. This situation has already had many effects on the human environment, including congestion, more energy consumption, pollution, traffic accidents, loss of time, delays, decrease in productivity and social costs [1]. After determining the main traffic jams in the urban area of Karachi, these negative effects can be minimized and then corrective measures can be taken to control these factors. In the last two decades, traffic in Karachi has grown significantly, due to the large population of the city, with a large number of owners and citizens who trade from one city to another. Although many infrastructures have been established in Karachi in the past decade, such as access, broad roads, bridges and unsigned corridors, the increase in traffic and other important factors is currently rapidly reducing these facilities and affecting the overall productivity of the system. There are psychological effects of these factors on humans like fatigue. It is predicted that if there has not been long-term planning done in advance, the worst situation will occur in the future. As a result, our economy will be seriously affected. A large amount of research has been carried out to regulate the movement of vehicles through manual or automatic signal installations, which results in an orderly flow of traffic. Despite the large investments in road infrastructure, traffic congestion, accidents, air and noise pollution in major cities are increasing to serious level. One of the basic problems of the Karachi bus service is poor management, especially the failure of the management and supervision on part of enforcement agencies [2].

The rapid increase in population has become one of the main causes of traffic problems and has caused serious issues and confusion in traffic management. Ultimately, it will have a negative impact on the economic development of Karachi and Pakistan [3]. Due to the privately-owned transport of citizens, the growing volume of traffic has become a growing problem in urban areas [4]. It is necessary to identify traffic jams on the roads of the city of Karachi and use geospatial technology to find alternative routes. In the past, many researchers have worked in the same related field, but due to the rapid changes in the structure of the city of Karachi and the growth of the population, more and more space and facilities for vehicles are needed. The difficulty of managing traffic is increasing, so long-term planning is needed, to protect the problems related to the future that should be achieved today. The main factors that affect traffic congestion were chosen as variables for this
study. The study of the choice of corridors and the application of Geographic Information System (GIS) in traffic management are also the main steps of the expected approach.

II. PROBLEM STATEMENT

Due to the random increase in traffic volume, urban traffic congestion has become a major problem in many streets of Karachi. Without considering the road infrastructure for optimal routing of transport system, the city’s existing public transportation system has brought great difficulties and mental torture to the Karachi’s people, as well as broader urban traffic problems such as air and noise pollution and congestion, which only compound the huge economic costs in the city. The people of Karachi have suffered a lot in the past. It also leads to deterioration in physical and mental health as well as quality of life. Therefore, the BRT was proposed to solve the problem of providing high-speed, reliable and convenient services to high-quality public transport systems. The idea behind BRT is to perceive it like Metro Train system as available in most of developed countries: it works in a unique way, at high speed and precision travel time and high capacity. However, this particular study will focus on identifying traffic congestions on the BRT route in the center of Karachi using geospatial technology.

III. STUDY AREA

The road network of Karachi was digitized using freely available satellite data in ‘ArcGIS’ software specifically highlighting the Green Line Bus Rapid Transit and its adjoining areas. The digitized road network with town boundaries is shown in Fig. 1.

![Fig. 1: Road Network of Karachi](image)

IV. METHODOLOGY

The methodology adopted for the study is:

i. Identification of parameters which affect traffic congestion.

ii. Selection of study corridor.

iii. Collection of data for existing road and passenger throughput.

iv. Prediction of passenger throughput considering BRT in operation.

v. Analysis of traffic density using GIS to predict combined effect of passenger throughput in conjunction with BRT.

We will see for last 6 year i.e., till 2016/2017 to determine the changes in traffic density as density is a function that is directly proportional to number of vehicles plying on road over a certain period of time and is inversely proportional to the throughput of road. Throughput includes number of traffic stoppages and width of road. More the width less is traffic density as there is more space for vehicles to ply. Narrower the width, keeping traffic constant, density will increase. Using the above-mentioned flow of methodology, it is intended to check passenger occupancy, road width, peak timings and number of vehicles per unit hour (influx and out flux). Also, it is intended to check number of people travelling in a vehicle for example in a car. If a car is only taking one or two passengers occupying one Passenger Car Unit (PCU) then obviously one bus occupying 3 or 4 PCUs is far better because it may accommodate around 50 passengers. It will result in 12 to 13 passengers per PCU which is much better than a car occupancy of 3 to 4 passenger for one PCU.

The methodology followed in thesis comprises of 3 major phases, i.e., the data collection, the processing phase and the compilation of results. Two sets of data were required to analyze the change in volume and behavior of road traffic on and around the Green Line BRT route before and after its construction respectively. The methodological flowchart is shown in Fig. 2.
In order to accurately assess traffic density or traffic flow, it is necessary to have fair estimates of the number and types of different types of vehicles plying on the roads and also show the road width or number of lanes available to them during various segments of their commute.

V. DATA COLLECTION

An extensive field survey was carried out to measure the road width of Karachi in 2018. The road width was measured using a laser range finder manufactured by ‘SNDWay’ which has a measuring accuracy of plus minus 2 mm. The equipment did not require calibration. Fig. 3 and Fig. 4 show pictures of the laser range finder and the field survey respectively.

The measurements taken thereof were also cross-checked using the satellite images of 2018 using Google Earth measuring tool. Since there was no field survey conducted in 2012 with respect to the width of the roads it was necessary to ensure that the measurements taken from the satellite imagery exhibited high accuracy when compared to the in-situ measurements. As the results were found to be fairly accurate, the road widths for 2012 were measured from Google Earth.

A. Vehicle Count

The 2012 vehicular count data was obtained from a survey conducted by Japan International Cooperation Agency (JICA), whereas the 2017 data for vehicular count was obtained from Sind Mass Transit Authority (SMTA).

In the 2012 survey, various types of vehicles were counted at a 15-minute interval for 16 hours at all major intersections along the then nonexistent BRT on a typical day. For ease of use this data was consolidated for a one-hour interval. Six major categories of vehicles were identified based on their sizes or uses, i.e. cars, rickshaws, motorcycles, pick-up lorries, minibuses, buses and trucks and the total number of vehicles of each category travelling through an intersection every hour was recorded.

In 2017 however the survey data for only 3 hours was available. Moreover, only a couple of road segments were the same as that of the survey conducted in 2012. This was due to the fact that SMTA had conducted this survey for the construction of the Red Line BRT and only some of the corridors were common with the Green Line. Therefore, the change of vehicle counts for each category of vehicle from 2012 to 2017 was calculated, averaged for 3 hours, and then extrapolated to create a 16-hour data set similar to that of 2012.

B. Traffic Density

The traffic densities for both the years under discussion were calculated in the following manner. Each class of vehicle was assigned a Passenger Car Unit or PCU weight-age. This weight-age was assigned based on the size of the vehicle in question and the space it would occupy on the road. Table I shows the PCUs assigned to every category.

| S# | Description | PCU |
|----|-------------|-----|
| 1. | Passenger Cars [Including. Jeeps & Station Wagons] | 1 |
| 2. | Taxies [Yellow & Black Cabs, Yellow Cabs & Radio Cabs] | 1 |
| 3. | Auto Rickshaws (Old Style & CNG 4-Stroke) | 0.7 |
| 4. | Motorcycles & Scooters | 0.5 |
| 5. | Contract Carriages including Suzuki | 1 |
| 6. | Large Public Busses [Intercity, UTS, KPTS etc.] | 4 |
| 7. | School Busses | 3 |
| 8. | Mini Busses | 3 |
| 9. | Coaches | 3 |
| 10. | Light Freight Vehicles [Pickups, Shehzore, etc.] | 2 |
| 11. | Single Unit Trucks [2 & 3 Axle] | 4 |
| 12. | Trailers | 4 |

The traffic density was then calculated using the formula shown in Eq. (1).
Traffic Density = \left(\frac{\sum_{i=1}^{n} P_n \times C_n}{RW/10}\right)

Where;
- n = Number of categories,
- P = PCU value,
- C = Count,
- RW = Road width in feet

Simply put, for every given segment of time, the numbers of vehicles counted in each category were multiplied with their respective PCUs. The results of all the categories were then summed up to arrive at the total volume of traffic for that time segment. This volume of traffic was then divided among the total number of lanes available on that road to calculate the total traffic density. For the purpose of this thesis it was assumed that each lane must be 10 feet wide. The resultant densities were then classified into categories ranging from 1 to 10 where 1 means very sparse traffic, 2 means light traffic, 3 means moderate traffic, 4 means dense traffic and 5 to 10 mean various stages of heavy congestion.

This calculation was repeated for 16 hours for both 2012 and 2017 data in order to generate thematic maps of traffic density along the BRT.

VI. RESULTS AND DISCUSSION

A. Road Width

A total of 238 road segments including U-turns were measured around 12 intersections along the Green Line BRT using a laser rangefinder and free satellite imagery for 2012 and 2017. It was noted that a fairly large portion of the width of the roads has decreased along the Green Line BRT route since 2012. Out of a total of 238 roads of the intersections along the BRT, 147 roads have shrunk in width, 74 have increased while 17 roads have remained the same. The average reduction in width is 6.28 feet and a maximum reduction of 20 feet was observed on some roads near Liaquatabad area. A reduction in road width due to the construction of BRT means that there are fewer lanes available for the traffic to commute on. Moreover, it was also observed that encroachments like permanent presence of pushcarts, rickshaw stands, etc., rendered the serviceability of the roads compromised.

B. Vehicle Count and Occupancy

The vehicular count for 6 different categories of vehicles was extracted from JICA and SMTA reports and then combined with the digitized shape files using the ‘Join’ functions in ArcGIS software to generate a geo-database for 16 hours of data. The combining factor of ‘matching IDs’ was utilized for this purpose. The same activity was repeated for 2012 and 2017. A sample segment of the resultant tables in geo-database is shown in Table II.

| Table II: Sample Table of Vehicle Counts on Various Intersections |
|------------------|---|---|---|---|---|---|---|
| Road ID | Car 11-12 | Rickshaw 11-12 | Motorcycle 11-12 | Pickup 11-12 | Mini- Bus 11-12 | Bus 11-12 | Truck 11-12 |
| 494 | 107 | 16 | 98 | 6 | 0 | 0 | 0 |
| 342 | 67 | 13 | 87 | 4 | 2 | 1 | 1 |
| 765 | 114 | 25 | 66 | 6 | 0 | 0 | 0 |
| 456 | 145 | 33 | 99 | 3 | 1 | 2 | 0 |
| 345 | 123 | 24 | 95 | 7 | 0 | 3 | 1 |
| 917 | 145 | 23 | 82 | 8 | 2 | 1 | 0 |
| 867 | 123 | 33 | 76 | 10 | 5 | 0 | 2 |

The observed number of occupants in different types of vehicles was categorized in 6 vehicle classes from the 2012 data and average occupancy per class of vehicle was computed. Under the assumption that occupancy remains the same over time, the average occupancy per class was multiplied with the count data of 2017 to compute occupancies for that year, as shown in Table III and Table IV.

| Table III: Average Occupancy in Different Classes of Passenger Carrying Vehicles |
|------------------|------------------|
| S# | Vehicle Type | Average Occupancy |
| 1. | Motorcycle | 1.2989 |
| 2. | Auto Rickshaw | 2.0959 |
| 3. | Car & Taxi | 2.3021 |
| 4. | Pickups | 6.9691 |
| 5. | Mini-Buses | 26.9843 |
| 6. | Buses | 44.0622 |

C. Traffic Density

Traffic density has an inverse relationship with the number of lanes provided that number of vehicle-PCU remains constant in a given time frame. Given this context, certain assumptions were made in the computation of traffic density for 16 hours along the traffic intersections along the Green Line BRT.

- Traffic is considered absolutely free flowing if the vehicles can maintain a constant speed of 30 km/h or 30000 m/h or 8.333 m/s.
- The intersections are the only hindrances in a free-flowing traffic.
- The average length of the intersections was found to be 100 meters.

Based on these assumptions a vehicle travelling at 8.333 m/s needs 12 seconds to freely pass the intersection:

100m/8.333 m/s = 12 seconds

Given that the data is hourly based, the following maximum number of cars that can freely commute on the roads was calculated:

1 hour = 3600 seconds

So 3600 seconds/12 seconds = 300 vehicles/lane/hr

Passenger Car Unit (PCU) equivalent values of major roads of Karachi were used from thesis submitted by Dr. Rizwan Ali Memon in 2001. The analysis of PCU values were carried out by comparing the average passenger car headway with the average headway of other vehicle types. Therefore, it was considered that every additional 300 vehicles per lane would render the class of traffic density change for that segment of the road. The traffic density maps were developed based on this reason with 10 classifications of equal interval of 300 as shown in Table V.

| Table IV: Sample Table of Passenger Occupancy in Various Vehicle Classes | |
|------------------|------------------|
| Average Occupancy | 44.0622 |
| | 26.9843 |
| | 2.3021 |
| | 1.2989 |
| | 6.9691 |
| | 1.0 |
| | 1.0 |
| | 1.0 |
| | 1.0 |
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| | 1.0 |

Table V: Sample Table of Passenger Occupancy in Various Vehicle Classes
Table V: PCU Table of Karachi [5]

| S# | Vehicle Type          | PCU Values |
|----|-----------------------|------------|
|    |                       | ID | OCP_Car | OCP_Rick | OCP_MC | OCP_PU | OCP_mini | OCP_Bus | TotalCCP |
| 1  | FROM GURU MANDIR TO NISHTAR PARK | 4046 | 7917 | 2738 | 3305 | 997 | 0 | 252 | 15209 |
| 2  | FROM GURU MANDIR TO TARIQ ROAD | 7352 | 12114 | 4530 | 5620 | 3045 | 769 | 682 | 27665 |
| 3  | FROM GURU MANDIR TO TOWER | 7362 | 125569 | 33479 | 103842 | 11233 | 19681 | 71468 | 374391 |
| 4  | FROM GURU MANDIR TO NISHTAR PARK | 7459 | 146601 | 48737 | 113672 | 15395 | 20450 | 72411 | 417166 |
| 5  | FROM LINES AREA TO NUMAISH | 7465 | 6995 | 8333 | 2242 | 1540 | 156 | 0 | 29267 |
| 6  | FROM LINES AREA TO TOWER | 7466 | 1739 | 671 | 731 | 91 | 36 | 157 | 3425 |
| 7  | FROM LINES AREA1 | 7477 | 8734 | 9005 | 12573 | 1531 | 192 | 157 | 32692 |
| 8  | FROM NISHTAR PARK TO GURU MANDIR | 7487 | 4301 | 1587 | 1349 | 836 | 0 | 52 | 8127 |
| 9  | FROM NISHTAR PARK TO TARIQ ROAD | 7483 | 19998 | 8881 | 4085 | 2890 | 96 | 157 | 2707 |
| 10 | FROM NISHTER PARK TO TOWER | 7489 | 4995 | 2385 | 2533 | 453 | 72 | 210 | 10814 |
| 11 | FROM NISHTER PARK1 | 7488 | 26295 | 7620 | 7967 | 3979 | 168 | 419 | 46448 |
| 12 | FROM NISHTER PARK2 | 6383 | 1255 | 1545 | 2000 | 606 | 35 | 0 | 6242 |
| 13 | FROM NUMAISH CHOWRANGI TO LINES AREA | 7534 | 12768 | 5592 | 7199 | 2816 | 648 | 682 | 29524 |
| 14 | FROM TARIQ ROAD TO GURU MANDIR | 7534 | 4078 | 2930 | 3829 | 1680 | 156 | 0 | 19172 |
| 15 | FROM TARIQ ROAD TO NISHTER PARK | 7544 | 48418 | 10366 | 14058 | 5143 | 7325 | 734 | 86644 |
| 16 | FROM TARIQ ROAD1 | 4932 | 7164 | 18587 | 25885 | 9638 | 7949 | 1416 | 135339 |
| 17 | FROM TOWER | 5188 | 94921 | 37247 | 56908 | 15771 | 24352 | 88134 | 316382 |
| 18 | FROM TOWER TO GURU MANDIR | 7560 | 7576 | 1808 | 4312 | 495 | 36 | 105 | 14732 |
| 19 | FROM TOWER TO NISHTER PARK (LEFT) | 4945 | 69070 | 6685 | 8623 | 4265 | 6833 | 524 | 94837 |
| 20 | FROM TOWER TO TARIQ ROAD (RIGHT) | 7446 | 3190 | 1815 | 3038 | 878 | 12 | 52 | 8789 |
| 21 | FROM TOWER TO TOWER | 952 | 173994 | 47155 | 72069 | 21409 | 31233 | 88276 | 434735 |
| 22 | FROM TOWARDS GURU MANDIR1 | 588 | 111990 | 44225 | 61645 | 19423 | 24821 | 88928 | 351032 |
| 23 | FROM TOWARDS NISHTER PARK | 4979 | 24671 | 7465 | 11647 | 3171 | 192 | 367 | 4913 |
| 24 | FROM TOWARDS TARIQ ROAD | 4930 | 97619 | 14897 | 19233 | 10001 | 7697 | 1363 | 150210 |
| 25 | FROM TOWARDS TOWER | 7446 | 184512 | 56183 | 125099 | 17918 | 27126 | 72621 | 483859 |
| 26 | FROM GURU MANDIR TO NUMAISH | 7460 | 83283 | 49366 | 77613 | 12740 | 18120 | 64449 | 302620 |
| 27 | FROM GURU MANDIR TO PEOPLES CHOWRANGI | 554 | 8329 | 2479 | 3001 | 2952 | 372 | 1258 | 18401 |
| 28 | FROM GURU MANDIR2 | 985 | 88612 | 51845 | 80619 | 15701 | 18492 | 65752 | 321021 |
| 29 | FROM JAHANGIR ROAD TO M.A.Jumma Road | 7456 | 67944 | 26015 | 45125 | 4844 | 3698 | 3732 | 151399 |
| 30 | FROM JAMSHED ROAD TO JAHANGIR ROAD | 2218 | 81747 | 38380 | 41246 | 15611 | 4059 | 6449 | 187492 |

VII. PASSENGER THROUGHPUT

All vehicles observed during the survey were categorized on the basis of passenger occupancy. For cars, motorcycles and rickshaws, the categories were based on absolute numbers. However larger vehicles were categorized as “only driver”, “half seats occupied”, “full seats occupied”, “half passengers standing”, “full passengers standing” and “passengers hanging”. These vague categorizations were given actual numbers based on average public transport vehicle sizes shown in Table VI.

Table VI: Vehicle Category Converted to Number of Passengers

| Vehicle         | Half Seats | Full Seats | Half Stand | Full Stand | Hang |
|-----------------|------------|------------|------------|------------|------|
| Pickups         | 5          | 12         | 15         | 18         | 20   |
| Mini-buses      | 13         | 25         | 30         | 33         | 35   |
| Buses           | 18         | 40         | 48         | 54         | 60   |

The calculations based on the numbers above show that in 2012 approximately 19.5 million passengers travel along the
intersections and the corridors alongside the Green Line BRT on a daily basis. This high number is probably due to multiple rides by the same commuters during the span of a day, when they go to and come back from work, schools, colleges, shopping, etc. In 2017, the number of commuter drastically increases to 30.9 million commuters. In 2012, motorcycles riders constituted the majority of the passengers with 23% of the share followed by cars with 20.4%. In 2017 however, 36.4% of the passenger load was being borne by cars, followed by motorcycles with 24.5% as shown in figure i.e., Fig. 5.

It may be worth mentioning here that cars have the worst average occupancy to PCU ratio, yet majority of the commuters prefer to travel in this mode of transportation. This may be due to a lack of other mass transit alternatives. It may also be noted that the passenger share of buses and mini-buses have also shrunk over the years probably due to their shabby conditions. The total number of passengers plying on different segments of the roads along the Green Line BRT daily, in different categories of vehicles, is shown above for ease of understanding.

VIII. CONCLUSION

Due to lack of a mass transit system, the people of Karachi have shifted over to their own means of transportation in the form of cars and bikes. Since the concept of a car pool system is lacking in our society, cars are usually travelling at much less than their optimal capacity resulting in very low average occupancy. Even with full occupancy the unfavorable occupancy to PCU ratio of cars, in turn has adversely affected the traffic density of the city. This congestion can only see some relief when, the BRT becomes operational and complies with comfort and proper scheduling standards, the other buses, mini-buses and pickups are removed from the roads and people start preferring using the BRT system.

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