APPLICATION OF OPERATIONS RESEARCH FOR TRAFFIC MANAGEMENT IN MUMBAI

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ABSTRACT

Mumbai, a city in India has been accounted for its heavy traffic congestion over the years. This traffic problem in Mumbai is generally a result of the poor infrastructure in the city, the lack of administration and the technological backwardness to control traffic as compared to other places around the world.

In our research paper, we initially discuss about other heavy traffic hit places in the world and their approach to resolve and control the congestion respectively. Having focussed on the 3 major setbacks mentioned above, we have analysed various OR techniques that could deal with each of the problem mentioned. The OR technique such as simulation can be used to set up real time models thus helping in making decisions regarding technology and infrastructure. Algorithms to deal with traffic problems, feasible technological changes especially in terms of traffic signals as well as traffic strategies have been analysed. Strategies regard changes in traffic administration are elaborated later. The major limitations our research had was the lack of data and statistics to find accurate solution and use the OR models efficiently. There is a high scope for research left in this area of study hence we have given some recommendations for further research on this topic. Thus, the research paper brushes on innovations in the traffic industry with infrastructural changes to manage the same. This would help in alleviating the traffic problem coupled with reduction in pollution thus pushing Mumbai towards a sustainable growth. The research paper deals with the traffic congestion problem in Mumbai and how the application of OR can help in managing the same.

Keywords: Traffic, Mumbai, Operations Research, Infrastructure, Technology, Administration, Ring Roads Simulation, Modelling, Strategies.

I.   INTRODUCTION

An average Mumbaikar wastes 11 days a year stuck in traffic, and this accounts for a loss of up to 17% to the GDP of Maharashtra. Excessive traffic also leads to more burning of fuel and emission of carbon leading to air pollution. According to (NEERI) road transport and railways contribute the most to the noise in the city. (Pachisia & Shah, 2020). Gufran Beig, the senior scientist and founder of SAFAR also said that the transport sector of Mumbai had a drastic rise in the last four years as a contributor to PM2.5 pollution in Mumbai. Moreover, the number of vehicles in Mumbai has crossed the mark of 40 lakh vehicles this year with 11.6 lakh private cars and 24 lakhs two-wheeler. While the road infrastructure has been same more or less. This has also led to a massive rise in traffic throughout Mumbai. The average time for a person to travel to work was merely 28 minutes in London across all modes of transportations while it can take more than an hour for the same in Mumbai. (transport, 2019) (Sen, 2020) The TTI for Mumbai was calculated as 2.21. TTI refers to the ratio of the travel time in peak hour vs nonpeak hour. which is very high. (Sen, 2020). This indicates explicitly that the traffic problems in Mumbai are significant and shall be worked on. Problems related to traffic management and traffic signal controls have been studied constantly for the past few decades. Based on these studies, various algorithms have been proposed considering the rapid improvement of traffic infrastructure. It has become much more important to study these problems with increasing traffic congestion. Traffic congestion, in itself, has been an important aspect of urban planning. It has become a serious issue in recent years due to the rapid increase in the number of vehicles on the road and transportation demand.

 It is the most crowded city in India and the ninth most crowded city in the world, with an estimated city population of 18.4 million. Along with the neighbouring regions of the Mumbai Metropolitan Region, it is one of the most crowded urban regions in the world and the second most crowded metropolitan area in the country, with an inhabitants of 20.7 million as of in 2011. It is also the wealthiest city in India and has the very best GDP of any city in South, West, or Central Asia. The city houses important financial institutions and therefore the corporate headquarters of various Indian companies and multinational corporations. It consists of two distinct

regions: Mumbai district and Mumbai Suburban district. The city district region is additionally commonly mentioned because the Island City or South Mumbai. Operations Research is one subject that has been used several times throughout history to solve complex problems in several sectors. Hence, we will be using Several operation research techniques and models to explore the potential solution for the problems. OR techniques in the field of traffic signal controls have been studied in the following research. Lack of technological advancements in dealing with traffic is a major setback in Mumbai as compared to other heavy traffic places. Simulation as a technique of Operations Research can be used to curb the deteriorating traffic situation in the city. It helps in estimating traffic flows and time, understanding the network systems, lays emphasis on alternate routes etc. Microscopic modelling helps identify the density, vehicle movement structure such as speed, space, sensitivity etc. which further serves in deriving plans. Macroscopic modelling helps to understand the aggregates measures of flow of traffic. With proper insights gained from simulation, development of better strategies to deal with Mumbai Traffic is possible. We also researched about administration changes that can be brought about to control traffic which includes developing roads, networks, utilizations of resources etc. We will be using simulation and technique of network models. Simulation technique involves setting up a stochastic model of a real situation or a project, coastal project in this case, then performing experiment upon it to predict the efficacy of the project and predict various situation that could take place and things they may have to reconsider or change. The same shall be used to test the efficiency of other phases of Mumbai coastal project. This can be done by using Maximum flow algorithm to make sure they number of vehicles, or the amount of traffic diverted is the maximum to reduce traffic. They could also use the shortest route algorithm to make sure they find the faster and the shortest route to move from one point to another. Moreover, this will also help them save cost majorly. Over the past 4 years Mumbai has consistently featured on TomTom's 10 most congested cities. Anticipatory vehicle routing can be helpful to reduce traffic congestion. The technique depends on delegate multiagent frameworks, which are a kind of climate driven coordination system. Individual cars are represented by agents in this technique, which issue lightweight agents on behalf of the vehicles to investigate other paths in the surroundings. Thus, it allows for vehicle routing to be directed based on traffic forecast information. Evidently, Mumbai is a city with very high traffic. But we find that there are very few steps taken to deal with this problem. Certain measures can bring about major positive impact on the traffic situation in Mumbai. Thus a research on how other countries deal with their traffic situations, the developments associated in terms of better administration and infrastructure along with inclusion of technological advancements and it's implication in Mumbai could give a new parameter in this regard and help solve the problem to certain extent making the life of people travelling in Mumbai easier and also serving in controlling traffic pollution. This research was undertaken to expand the scope of betterment in this regard and to get an overview of how OR can help tackle the Mumbai traffic. The research paper begins by stating the measures undertaken by various countries to control traffic from various literatures. Later the objectives of the paper have been mentioned followed by the analysis and findings which include various OR strategies to combat the traffic issue in Mumbai majorly in 3 aspects- infrastructure, technology and administration. The limitations of the research paper along with the reccomendations regarding the entire problem have been provided just before the conclusion derived.

II.   LITERATURE REVIEW

Transportation in metropolitan spaces of India is exceptionally intricate, because of the system frameworks, the enormous number of destinations, and the assortment of traffic. Mumbai is typical of these issues. Due to urbanization , the city is confronting an extreme traffic issue predominantly because of a restricted transport infrastructure, a quick expansion in vehicle proprietorship, poor administrations, traditional way of handling etc. This study will analyze the control of Mumbai traffic. The problem identified in Mumbai as compared to other countries is the traditional way of traffic control. Moscow is one such place having resemblance with Mumbai traffic. Moscow came up with a technological transition which served it in controlling traffic. It introduced The intelligent transport system takes into consideration observing and controlling traffic, anticipating traffic circumstance, and offsetting street limit with real traffic flows. The cameras are associated with a central control and observing room at the Moscow Traffic Management Center, where a tremendous advanced data screen shows ongoing pictures of traffic developments and data on the genuine conditions on

the streets. Mumbai too can develop such advanced technology to control and co-ordinate the traffic. (AIJAZ, 2017**)** It has also developed a ARTEMIS System which can be adopted by Mumbai. Connecting devices through traffic controllers, detectors and communicator networks works on basis of prediction resulting into autonomous regulation of traffic signal reducing waiting time. (Successful Introduction of Advanced Traffic Signal System in Russia, 2017). TrafiCam x-stream vehicle presence sensors is can be installed in Mumbai especially at busy road junctions just like in Moscow. By identifying both pausing and approaching toward vehicles, these smart all-in-one cameras will be utilized for the enhancement of traffic light timings. These are great alternatives to inductive loops. The camera had no issues with the pollution in Moscow and thus can be a great set up in Mumbai as well. (Smart traffic sensors help alleviate city congestion in Moscow, Russia, 2017) With reference to these, Mumbai can estimate the traffic using Operation Research techniques. The purpose of this research paper is to understand the current shortcomings in the traffic control system in the city of Mumbai and the various solutions that can be used to tackle the same. At present, Mumbai is the most crowded city in India, with an estimated population of 18.4 million. (Abhyankar & Pawar, 2016) Mumbai is listed in the top 10 most congested cities in the world, according to the 2019 TomTom Traffic Index. Chokepoints along Mumbai's major routes contribute the most to high costs of congestion. Driving speeds on side lanes has decreased significantly with commuters facing less than 8km per hour speeds on certain roads. (Pachisia & Shah, Hindustan Times, 2020)**.** While there has been significant research on infrastructural developments to improve traffic control in Mumbai, few researchers have taken technological advancements into consideration. Many first-world countries have been successful in introduction technological changes to improve the flow of traffic on their respective roads. Almost all Chinese cities with a population above 2 million have installed red light cameras and CCTV traffic surveillance with centralized traffic management centres. In Singapore, significant efforts have been made to harness technology in order to maximise network capacity. One example of the same is the upgradation and installation of intelligent traffic light systems. (Abhyankar & Pawar, 2016). There are various reasons for the lack of Intelligent Traffic Systems in Indian cities. These include lack of user awareness, low interest in decision making, improperly developed road networks and lack of resources for proper functioning and maintenance of roads. (Patil, Mandhare, & Kharat, 2018)

"An average Mumbaikar spends about 11 days a year stuck in the traffic jams". This wastes a lot of their time and also affect their productivity levels. This causes about 17% loss to the gap of Maharashtra. (Pachisia & Shah, 2020**)** The traffic also leads to increase burning of fuel and of air and noise pollution. Hence, changes in the road infrastructure of Mumbai are essential. So one solution to the above stated problem could be developing a ring road. A ring road or a beltway refers to a circumferential route made using a series of roads within a city. It plays a vital role in urban planning system. With this road, the traffic doesn't need to pass through the centre of the city. This significantly helped several cities similar to Mumbai to handle the traffic flow and support urban infrastructure planning.(NSIALA & WATANABE, 2020). In Japan, it worked efficiently to reduce the traffic by diverting the unwanted traffic away from the city centre. It also served as a high-capacity transport system and improved connectivity to the main functions of the city like the city centre and industrial areas.(NSIALA & WATANABE, 2020). This was also made in cities like London, Moscow, and Munich. Even though they weren't made with the intention of managing traffic flow as there were no traffic problems when it was created. It helped them decentralise the movement of traffic by giving alternative routes for the traffic flow, in the present times. (Tatiana, Andrey, & Arthur, 2020) The same strategy can be used in Mumbai. We can use the model of network analysis for the planning of the ring roads, and we can use simulation models for predicting the efficiency of the ring road in Mumbai. Moreover, foresee any potential problems that could arise. A similar structure to a beltway is being developed in Mumbai - the coastal project. It is predicted that it will divert the traffic of the city centre to these routes and reduce traffic as well as transportation time. However, many researchers have predicted that it won't be efficient and there is a higher opportunity cost in the development of the coastal road. Hence, they shall consider the formation of ring road and also use OR techniques such as Simulation and network analysis to predict the efficacy of the project. Along with this, another strategy that can be applied is the GIS or the Geographic information system software. This can be used to analyse the transportation network to aid in planning relieving traffic congestion, reducing pollution and forecasting the demand of transportation which will help improve the planning of the road infrastructure.

(Arora & Pandey, 2011**)**. Since Tokyo has similar demographics as compared to Mumbai , some of these policies mentioned below on development of infrastructure to reduce traffic congestion can be looked up and formulated by the concerned authorities in Mumbai . The bureau of construction of Japan has formulated several policies on development of infrastructure to reduce traffic congestion . The Bureau will build the three ring expressways, which support all of Japan's social and economic activities, to ensure a smooth flow of traffic in the Greater Tokyo Area. The Bureau will support the building of intersections and road safety infrastructure, as well as the conversion to grade-separated railway crossings, to improve the smooth flow of traffic on roads and boost the degree of safety on both roads and railways. To maintain Tokyo residents' way of life and secure their safety, the Bureau will improve the living environment in urban areas by building arterial roadways that enable a smooth flow of traffic locally (Bureau of Construction, n.d.)

From a short-run perspective, regional decentralisation and timewise equilibration of traffic volume are examined further (Sugiyama, 1989). Traffic congestion is a major problem for Mumbai so Anticipatory vehicle routing can also be potential solution in this regard, as it allows for vehicle routing to be directed based on traffic forecast information. The technique depends on delegate multiagent frameworks, which are a kind of climate driven coordination system. Individual cars are represented by agents in this technique, which issue lightweight agents on behalf of the vehicles to investigate other paths in the surroundings. The cars then issue light-weight agents for allocating road segments, spreading the vehicles' goals, and coordinating their behaviour based on the appraisal of the alternatives (D. Weyns, T. Holvoet and A. Helleboogh, "Anticipatory Vehicle Routing using Delegate Multi-Agent Systems," 2007 IEEE Intelligent Transportation Systems Conference, 2007) The paper talks about the issues associated with control in Mumbai and therefore the thereby presents the solutions needed to tackle them. The current residents of Mumbai, the lifeline of Maharashtra is estimated to be over 22 million people. The town ranks at number 6 spot in terms of most populated cities within the world. Mumbai has witnessed an economic boom since the liberalization of 1991, the finance boom within the mid-nineties and thus the IT, export, services and outsourcing boom in 2000s. Many of India's numerous conglomerates are based in Mumbai which has led to increased purchasing power of bourgeoisie . The amount of vehicles in Mumbai has crossed 25 lakh, with most of them being registered within the past decade. Consistent with data from regional transport offices (RTO), a whole of 25,02,673 vehicles are registered within the smallest amount three centre — Tardeo, Andheri, Wadala till March 31, 2015. This includes 7.57 lakh vehicles within the island city, 11.71 lakh within the western suburbs and 5.73 lakh within the eastern suburbs. While 14.30 lakh two-wheelers were registered, 8 lakh were cars. And conveyance within the city, the amount of BEST buses, taxis and autorickshaws registered stood at just 1.86 lakh. This data reveals Significant increase privately vehicles. Due to shortage of Parking spaces, people tend to park vehicles on roads occupying large portion of road space required for movement of traffic causing inconvenience to vehicular flow and reducing road capacity. In terms of administration, many roads are being improved in Mumbai. They're either closed entirely or certain lanes are closed for traffic movement. During this case commuters need to take diversions which cause delays. The author suggests various short term and future methods to tackle the traffic issue. To sum them up during a conclusive manner- Providing north-south and east-west rail and road connectivity within the sort of ring rails and ring freeways. All world-class cities have express ring freeways (6-8 lane roads with no signals) round the city such a freeway are often accessed from any point within the city in but ten minutes. Government has proposed various Metro Rail Lines, Coastal Road, Flyovers. But timely completion of those projects are necessary. A government should give priority to enhance conveyance which should provide the simplest services at a minimum cost because as conveyance will improve, the people will refrain from using private vehicles. Also combination of short term measures like improving junctions, completion of missing links, Road widening, improving quality of roads & railway networks, exploring the utilization of water transport & future measures like politics would minimise the issues of traffic in Mumbai. Therefore, our main objectives for the research paper, that we intend to do using the tools in operation research, revolves around the following:

1. Effective ways to improve the infrastructure or the city to reduce or divert the city traffic.
2. Technological advancements that can control traffic in Mumbai.
3. Explore Administrative ways to reduce the city traffic and improve traffic management of Mumbai.

III.   ANALYSIS AND FINDINGS

Infrastructure

Ring Roads & Mumbai Coastal Project We have used both secondary and primary data to find out the impact of traffic on them. The secondary data was by means of research papers and online articles and the primary source is survey. The sample size of the survey was of 50 people who were residents of Mumbai. They were of the age 18+ and the pool of interviewee were chosen randomly to see the overall effect on different types of people in the city.
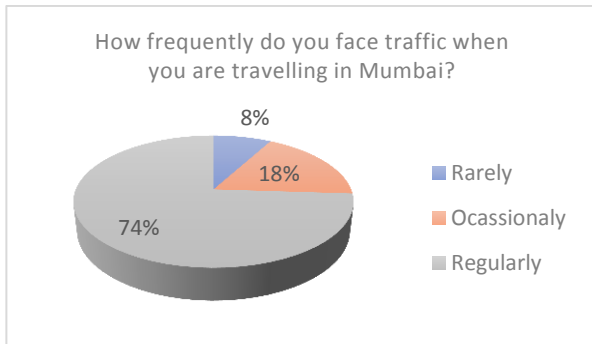
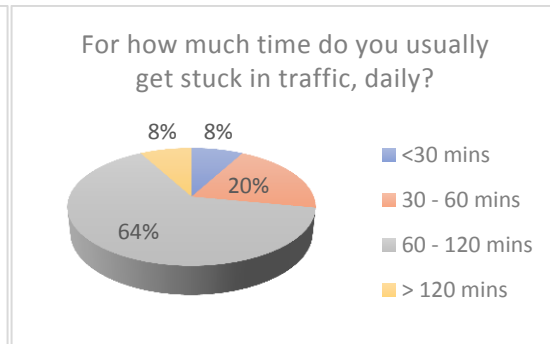

Figure 1: Response of the survey question 3

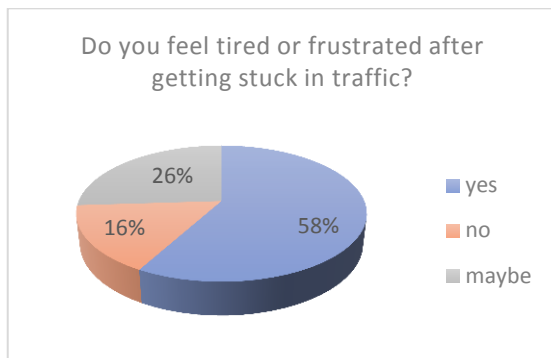**Figure 2:** Response of the survey question 4

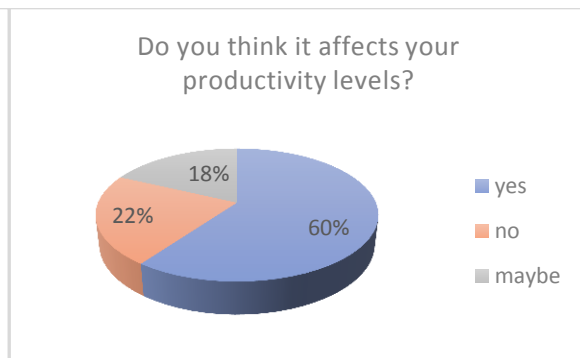**Figure 3:** Response of the survey question 5

Figure 4: Response of the survey question 6

Implications of the survey responses:

1. We can see that out of those 50 people about 74% of them faces traffic regularly, as seen in figure 1.
2. The figure 2 shows that about 92% of them face traffic of more than 30 minutes every day and 64% of them faced traffic of 1-2 hours regularly and about 4 of them get stuck in traffic for more than two hours daily.
3. As seen in the figure 4 and figure 5, out of 50 people, 58% of the people feel tired and frustrated after they are stuck in the traffic and 30 people think that it affects their productivity levels.

It was also mentioned before that an average Mumbaikar wastes 11 days a year stuck in traffic, and this accounts for a loss of up to 17% to the GDP of Maharashtra. Excessive traffic also leads to more burning of fuel and emission of carbon leading to air pollution. The honking on the road also leads to noise pollution. (Pachisia & Shah, 2020) This proves that Mumbai traffic needs to be controlled. According to the stats the most traffic in Mumbai is city center. Ring roads could be a solution to this. A ring road or a beltway refers to a circumferential route made using a series of roads within a city. With this road, the traffic doesn't need to pass through the centre of the city. However, looking at the geography and demographics of Mumbai, which is similar to island, it makes it difficult to make a ring road around it hence Mumbai has come up with a similar alternative. Mumbai is also developing a beltway of a similar kind- coastal road which aims to divert the city traffic to these roads. However, researchers believed it won't solve the traffic problem effectively. Hence, they shall use certain Operation research techniques, in order to ensure and test the efficacy of the project or to find an alternative route of the coastal project. This can be done via Simulation. This technique involves setting up a stochastic model of a real situation or a project, coastal project in this case, then performing experiment upon it to predict the efficacy of the project and predict various situation that could take place and things they may have to

reconsider or change. The same shall be used to test the efficiency of other phases of Mumbai coastal project. For this they will have to take a lot of factors into accounts like the entry and exit points, several statistical figures like traffic flow at different areas, effect of the entry and exit points on the traffic levels at different points etc. This will help them chose the locations accurately and identify the best route. According to the plan, it will divert only 60000 of the vehicles per day which is only about 5% of vehicles in Mumbai. **(**Indorewala, 2019) Hence, they shall use Operation research technique of network models. This can be done by using Maximum flow algorithm to make sure they number of vehicles, or the amount of traffic diverted is the maximum to reduce traffic. They could also use the shortest route algorithm to make sure they find the faster and the shortest route to move from one point to another. Moreover, this will also help them save cost majorly. Another solution for this could be making sure that the government makes places for parking of the cars. Many of the cars are left for parking on either side of the road which reduce the width of the roads leading to traffic. There shall be an infrastructure like a parking lot nearby every area, especially in area with high traffic, so that vehicles won't be parked on the road, and this will reduce the traffic. Lastly, they shall also look at other alternative then the Mumbai coastal project. It is said that the per km building cost for the Mumbai coastal project is 25 times higher than the Mumbai metro and it will only carry 6% of the population of what Mumbai metro could carry. (Indorewala, 2019) Looking at these figures, the officials can reconsider their decision and allocate their decision wisely as this alternative could reduce traffic more significantly. Moreover, thinking about the long term and pollution point of view, it would be wiser to reduce the number of people using private cars and encourage them to use public transports such as metro. This will solve many problems like traffics and pollution levels in the Mumbai, which is one the highest in the world.

Three Ring Expressway and anticipatory vehicle routing

Mumbai has still not completely realized the importance of development of infrastructure to reduce traffic congestion. They have not formulated policies unlike Tokyo. They need to identify the infrastructural drawbacks and build ring expressways, arterial roadways, and intersections. This will also a part in securing the safety of Mumbaikars. Mumbai should research upon potential solutions for the same. They can resort to using anticipatory vehicle routing for the same as it allows for vehicle routing to be directed based on traffic forecast information. There will be some complications regarding the installation and effectiveness of it, but it is the need of the hour. Hence there is a lot of scope of study on infrastructural development techniques. Anticipatory vehicle routing as a technique of OR can help reduce traffic congestions to a good extent

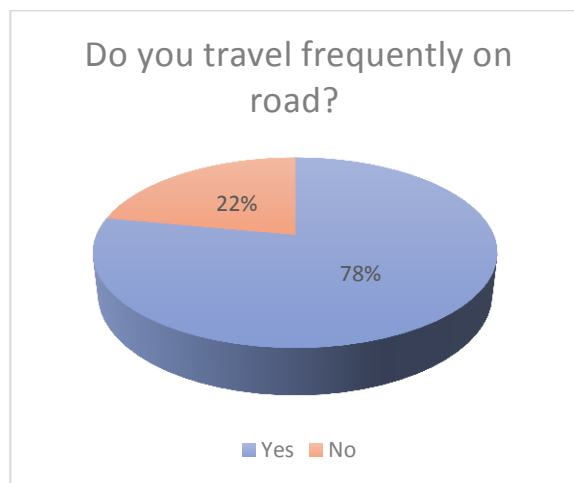## Appendices

Figure 5: Response of the survey question 1

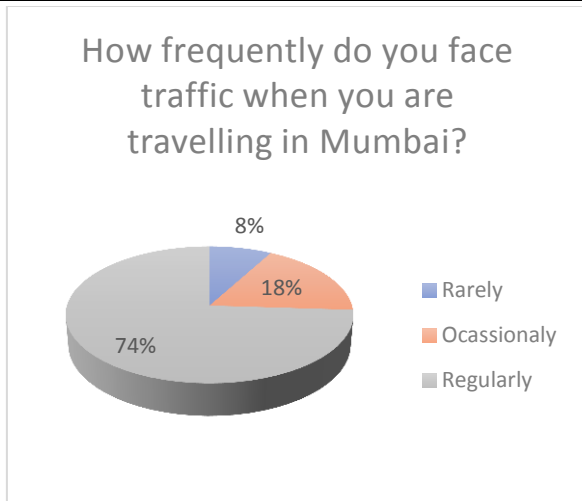**Figure 6:** Response of the survey question 2

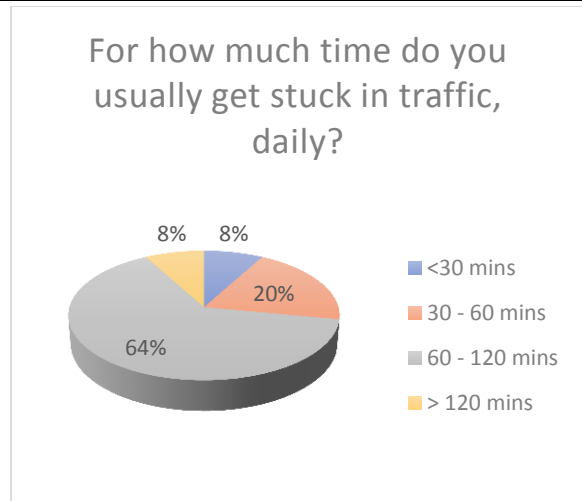**Figure 7:** Response of the survey question 3

Figure 8: Response of the survey question 4
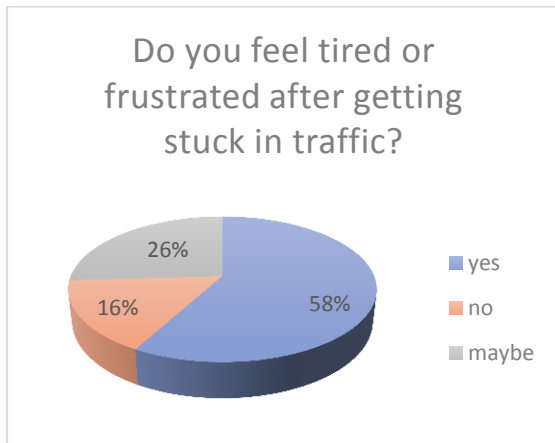

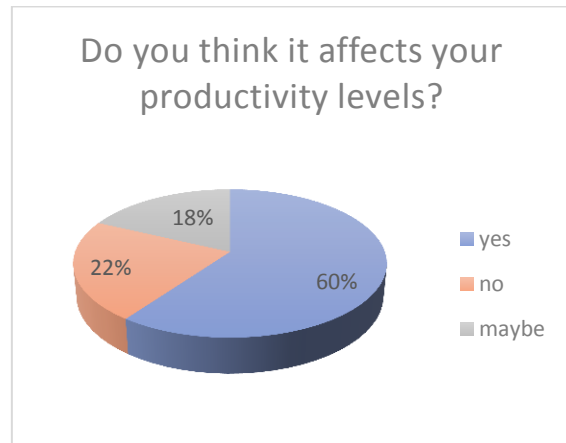**Figure 9:** Response of the survey question 5

Figure 10: Response of the survey question 6

IV.   TECHNOLOGY

Traffic Simulation

The major problem identified in the drawbacks of controlling and regulating Mumbai traffic is the traditional way of handling it. Mumbai doesn't rely on technologically driven intelligent systems based on detecting, controlling, and predicting traffic to control it. Like Moscow dealt with the traffic problem using advanced technology, similarly Mumbai can replicate it too. So, the identified problems that cause traffic is technological drawbacks for traffic control. Unlike Moscow, Mumbai has very little exposure to intelligent transport system that anticipates the traffic depending on the street circumstance. Unlike ARTEMIS, the traditional signal system holds traffic and increases waiting time in Mumbai without any predictions that result into autonomous regulation of traffic. To solve this problem, Mumbai can resort to some Operations Research techniques such as Simulation to identify the traffic, recreate it and decide accordingly. Traffic simulation is a technology that is used to study, design, and create traffic networks and systems. This can help us estimate the traffic flows, alternative routes, elements of road such as link, merges as well as estimating time and cost thus devising reduction in traffic congestion in Mumbai

Through microscopic modelling, we can analyze the flow, density, travel time, speed, and other characteristics of various vehicle movements. The car following model under this category identifies the relationship with the lead vehicles as a function of space, speed and acceleration. In Mumbai, the sensitivity reaction of the vehicle to leading vehicle is high due to closeness in high density roads such as Andheri, Ghatkopar, Kurla, Muhammad Ali Road etc. as well as due to high speeds on expressways. The lane changing model by Gipps can also help in developing simulations.

Through macroscopic modelling, aggregate measures of speed, flow and density identify traffic. On high density roads of Mumbai like the ones mentioned above, we can develop a simulation based on the Greenshields's model, high density- low speed and low density – higher speed (Azlan & Rohani, 2017)

Thus, Simulations as a technique of OR can be used to demonstrate real life traffic situations of Mumbai. Simulating models as per time constraints like the heavy traffic moving towards southern Mumbai in the daytime and northern Mumbai in the nighttime can guide in creating predictions and based on that, the traffic control team in Mumbai can co-ordinate. The signal light timings can also be worked upon depending on the traffic at a particular day. Thus, traffic simulations developed in Mumbai can resolve the problem to an extent.

Traffic Signal Controls

Traffic congestion has always been a very crucial aspect of urban planning. However, it has become a serious issue that needs to be addressed due to the rapid increase in the number of vehicles and transportation demand. Traffic signal control is an extremely important tool used in management of traffic flow as it is considered to be one of the most effective ways to reduce traffic congestion, especially at intersections. (Eom & Kim, 2020)

Mumbai is notorious for being one of the most congested cities in the world. Upon conducting research, various spots in the city were found to be the most problematic traffic junctions

1. Senapati Bapat Marg
2. Goregaon Bridge
3. Powai Vikhroli
4. Teen Hath Naka

One common problem identified in the listed areas, apart from the huge number of vehicles, was a lack of high-quality traffic signal plans to regulate the traffic. According to this, 3 major traffic strategies can be used when attempting to solve a traffic signal control problem.

1.   Fixed-time Strategy

In this strategy, there is an establishment of optimal signal plans for fixed signal phase sequences with only a set time duration for every single phase. Adopting this strategy assumes that the traffic demand remains constant at all times to calculate the best possible signal plans based on historical traffic information.

2.   Actuated Strategy

Under this, real time data is collected from infrastructure- based sensors and a simple logic criterion is applied such as green light extension, gap out or max out.

Green light extension prolongs the green light phase based on the rate of traffic flow. In gap out, a particular light phase is terminated when the time interval between consecutive activations of a vehicle detector exceeds a set established threshold. Max out terminates the green light phase when it exceeds the pre-established maximum green phase duration.

3.   Adaptive Strategy

This is very similar to the actuated strategy, except that it utilises the predicted traffic conditions in the near future. Because these strategies require highly accurate prediction algorithms as well as good signal plan optimization, developing algorithms based on an adaptive strategy could be more difficult when compared to an actuated strategy. For Mumbai, the best possible strategy would be the adaptive strategy due to the constantly changing traffic levels in the city.

V.   ADMINISTRATION

To come up with an analysis in order to solve Mumbai's traffic problem, what is needed is : Systematically developing 4-5 emerging Central Business District (CBDs) and improving their connectivity with each other and with key residential areas. This will reduce the current north –south pressure to and from the Nariman Point CBD, For example creation of Bandra-Kurla Complex. It is a planned commercial complex within the suburbs of the Indian city of Mumbai. The complex is that the first of a series of "growth centres" created to "arrest further concentration" of offices and commercial activities in South Mumbai. It is expected to reduce the congestion in south Mumbai and seed new areas of planned commercial land within the metropolitan region.

There is need to explore and create such more complexes in the area like Andheri, Goregaon, Malad, Kurla & Vikroli etc. Providing north-south and east-west rail and road connectivity in the form of ring rails and ring freeways. All world-class cities have express ring freeways (6-8 lane roads with no signals) round the city such a freeway are often accessed from any point within the city in less than ten minutes. Government has proposed various Metro Rail Lines, Coastal Road, Flyovers. But timely completion of those projects are necessary. For example, Goregaon – Mulund Link Road (GMLR) has been delayed for an extended. A government should give priority to improve Public Transport which should provide the best services at a minimum cost because as Public Transport will improve, the people will refrain from using private vehicles. Also combination of short term measures like improving junctions, completion of missing links, Road widening, improving quality of roads & railway networks, exploring the use of water transport & long term measures like policy making would definitely minimize the problems of traffic in Mumbai city. Traffic problem is something which is increasing on a daily basis and situation is not getting any better. Hence there is a lot of scope for future study. Comprehensive efforts from Government and its various agencies, transport planners, car manufacturers as well as from common public is required. Study in the field of quality of roads, improvement in rail networks, use of water transport, mass rapid transit systems, alternative energy vehicles, innovation and use of modern technology, innovation and use of road safety measures and many more can be done.

VI.   LIMITATIONS

Certain limitations restrict the accuracy of the research. There could be a few limitations in the survey as like the size of the survey was very small to establish the problems and analyse the data of such a big city and the no of people that are affected in it. Moreover, the questions could have been misinterpreted or the answer given by them could have been inaccurate. Also, another limitation of this research is that the simulation is yet to be used to see the results. It needs a lot of data and statistics which isn't available currently. Building ring expressways will require huge amount of capital and will have negative impact on environment which is not considered in the research paper. The estimated capital is not calculated as it depends on the project size. The installation of anticipatory vehicle routing can have certain complications. Mumbai is a heavily populated city. Thus, the vehicular pollution is on a rise. This can damage the camera installations and sensors. The unpredictable nature of accidents and rains also restrict the simulation model to work with accuracy. The change in work timings, holidays, lifestyles also hamper the data collected for simulations. In this research, it is assumed that the traffic on the roads and intersections of Mumbai consists only of passenger cars, transit vehicles, bicycles, pedestrians, emergency vehicles, heavy goods vehicles, and large goods vehicles.

VII.   RECOMMENDATIONS

To improve the traffic management in high demand situations, the recommended measures need to be powerful and impactful. The measures should be co-ordinated properly and deployable at the earliest. A transition from reactive traffic management to proactive traffic management is very crucial in the city of Mumbai. A greater role is required for route-guidance and traffic controls. As self-driving vehicles increasingly become a possibility, phase sequence of traffic signals will no longer need to be improved as machines do not get confused. More research considering autonomous vehicles is necessary in the field of traffic signal controls. Currently, there is no standard which effectively compares the performance of different traffic signal control models as there is no unified simulation framework. A set of benchmarks regarding the same need to be developed to introduce standardisation. (Eom & Kim, 2020). Along with simulations, auto-generating connectors that communicate the identified real traffic situation could lead Mumbai traffic operations. The installations of advanced cameras that are driven by sensors at heavy traffic roads on Mumbai could be one way of automating traffic and waiting time. Further analysis on lane changing model can bring about a positive transition in Mumbai traffic.

Another recommendation is to spread awareness in the city to use means like public transport to decrease the number of cars on road hence reduce traffic. They shall also use methods to encourage the usage of cycles to reduce the usage of any vehicle. This has worked in several cities to reduce traffic, pollution and improve their health and productivity levels. They shall also improve the public sector infrastructure like buses and local trains to motivate people to use the public transport. They can also make use of the upcoming Mumbai metro

and make sure they have it connected across the city to reduce usage of cars in the cities hence reduce traffic and travel time. Traffic problem is adding up on a daily basis and it's becoming from bad to worse. Hence there's tons of scope for future . Comprehensive efforts from Government and its various agencies, transport planners, car manufacturers as well as from common public is required. Study in the field of quality of roads, improvement in rail networks, use of water transport, mass rapid transit systems, alternative energy vehicles, innovation and use of modern technology, innovation and use of road safety measures etc. can be done.

VIII.   CONCLUSION

The purpose of this research was to identify effective strategies for dealing with traffic congestion. Based on the analysis it can be concluded that building ring expressways, intersections and arterial roadways in Mumbai will help to reduce traffic congestion to an extent just like it did in the case of Tokyo. Infrastructural development is the key to reduce traffic congestion. Timewise equilibration of traffic volume can be examined and thought about. Techniques like anticipatory vehicle routing is a very potential solution to this and thus can be very helpful in this regard. Simulations can also be helpful to determine the real traffic situations. Based on the details collected through this method, we estimate the traffic which further bring inputs through sensors, detectors, and communicators. Through such technological advancements incorporated, traffic network system is predicted and controlled thus leading to better traffic operations in the city. The future traffic situation of Mumbai seems to be positive with inclusions of advanced technology and A.I. They can use it to predict the efficacy of the project and predict various situation that could take place and things they may have to reconsider or change like the entry and exit points. This is left for further research as for the simulation several statistics and probability is required which are currently unavailable. Moreover, thinking about the long term and pollution point of view, it would be wiser to reduce the number of people using private cars and encourage them to use public transports such as metro. This will solve many problems like traffics and pollution levels in the Mumbai, which is one the highest in the world. They shall also improve the public transport infrastructure to encourage People to reduce the usage of private cars hence reducing traffic. Various administrational changes require lot of capital investments but these changes can bring about traffic control in the city. Thus, OR could be useful to tackle the Traffic in Mumbai in 3 major aspects of infrastructure, administration and technology. Traffic Management options could also be adopted by City police. Leadership and civic agencies to achieve traffic decongestions in all Indian cities. While some Recommendations are often implemented within the short run, some would require an extended term perspective. If implemented systematically these sustainable measures will go a long way in making transportation our city more convenient and fast.

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