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Traffic Congestion A Pilot Study of Kanpur

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ABSTRACT

This paper aims to explore road transport congestion, examining its mathematical, engineering, and economic underpinnings. It will discuss tools for measuring urban traffic congestion and its economic impact on businesses. The study will analyse congestion and mitigation strategies in different countries and cities to identify optimal solutions, potentially including a case study on Kanpur. A literature review of articles published between 1995 and 2020 forms the basis of this research. The thesis will detail various congestion mitigation measures, such as tolling, intelligent traffic signals, public transport promotion and improvement, road enhancements, demand reduction, economic and regulatory policies, land use planning, and future technologies like flying cars, and will suggest appropriate measures for different types of congested areas.

Introduction

Traffic congestion, a major issue in metropolises, is characterized by reduced speeds, longer travel times, and queues, often stemming from the sheer volume of vehicles exceeding road capacity or sporadic disruptions. This discrepancy between expected and actual road performance leads to both persistent and intermittent congestion. Efficient road networks are crucial for social organization, yet congestion is a common experience, causing delays for both vehicles and pedestrians. Identifying congestion characteristics is vital for effective transit planning. Congestion negatively impacts the movement of people and goods, wasting time and resources, increasing pollution and stress, and reducing overall efficiency. Its causes are broadly categorized as micro-level (related to individual vehicle interactions) and macro-level (system-wide factors). While seemingly an obstacle, traffic congestion is also a byproduct of the fundamental need for many people to travel simultaneously for work, education, and daily errands, a demand difficult to alter without significant societal and economic consequences. This article aims to analyse the definition, causes (both micro and macro), problems, and mitigation strategies for traffic congestion.

Objective

The objective of this thesis is to investigate congestion in road transport. To analyse the methodology for measuring it, determine why it is preferred, and identify measurement tools. To delve into the engineering and economic theories related to congestion. To find optimal solutions for mitigating it. A pilot study on congestion will be conducted in Kanpur.

Literature Review

Traffic Congestion in India and Worldwide

Traffic congestion in major Indian cities like Mumbai, Bengaluru, Delhi, and Pune was nearing pre-pandemic levels by early 2021, with Mumbai ranking second globally. While Bengaluru topped the congestion charts in 2019, these Indian cities consistently feature high in global rankings. This persistent peak-hour congestion in growing metropolises is likely to worsen due to increasing population and wealth, a trend often linked to economic growth. Various factors contribute to this, including accidents, disabled vehicles, construction, large gatherings, bad weather, and emergencies. Although complete eradication of rush-hour congestion is unlikely without severe economic downturns, combined mitigation efforts can slow its progression. Current relief for commuters often comes from in-car comforts. In India, traffic congestion is a significant challenge for transportation professionals, exacerbated by poor road conditions, mixed traffic, lack of lane discipline, and uncontrolled parking, despite rapid road construction. Efforts to measure increasing congestion are lacking due to funding limitations for infrastructure expansion. To help commuters, radio broadcasts, electronic signs, and smartphone apps provide real-time traffic information, including visual cues and potential detours via GPS.

Types of Congestion

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Methodology

To mitigate congestion, we must first be able to calculate it. There are several methods for measuring it. Various tools exist for this purpose. Various engineering and economic factors are involved in measuring it.

Tools and Terms for Congestion Measurement (Akele, G. A., Akele, M. U., 2018)

Traffic Volume Counts: Only during the number of peak flows, determined by a twelve-hour traffic volume count, traffic volume counts are conducted at major intersections and critical junctions. The amount of traffic is measured in units of vehicles per hour (PCU/h).

Roadway Capacity

C = 3600/t(m) + t(s)

Where c denotes the capacity of a particular access or lane (veh/h). On the access or roadway, ts = average time in service or service delay (sec). tm represents the average climb time (seconds).

Total delay: The time interval between when a vehicle enters a queue and when it leaves the stop line can be used to calculate the total delay for each individual vehicle.

$$D = \sum_{i=1}^{n} L_i \times \frac{15}{3600}$$

Where D represents the total delay (veh-h); n = number of 15-second intervals in an hour (3600/15); Li = observed queue length in interval I.

L = d * V / 3600 = Queue length.

Where L = average queue length (veh); d = average total delay (sec/veh); V = traffic volume (veh/h).

Delay and Capacity

$$d = \frac{3600}{c} + 900T\left[\frac{v}{c} - 1 + \sqrt{\left(\frac{v}{c} - 1\right)^2 + \frac{\left(\frac{3600}{c}\right)\left(\frac{v}{c}\right)}{450T}}\right]$$

Where d denotes the overall average delay (veh/veh). V = traffic volume per hour (veh/h). C is the number of vehicles that can be moved per hour (veh/h). T is the number of hours during which the study will be conducted.

Congestion Severity Index (CSI)

Indicates the vehicle-hour loss per thousand kilometres travelled.

$$CSI = \frac{\text{Average Total Delay (Sec/Veh)}}{\text{Traffic Queue Length } (Veh)}$$

Traffic growth rate: Used in two different years to determine this by comparing traffic data collected at the same locations.

$$P_f = P_p(1 + r)^n$$

Where Pf denotes the amount of traffic that will occur in the future. Pp = Past traffic volume; r = Decimal growth rate; n = Years between previous and predicted traffic data.

Mobility level: The volume-capacity relationship is used to calculate the mobility level of an individual link. (Akeke, G.A. & Akeke, M.U. & Okafor, F.O. & Ezeokonkwo, J.C., 2018)

Table-2.1. Scale of Different Mobility Levels

Level of Mobility	Volume / Capacity
Tolerable	<0.85
Moderate	≥0.85<1.00
Serious	≥1.00<1.20
Severe	≥1.20

(**Source:** Highway Capacity Manual (HCM) [1])

Measuring Urban Traffic Congestion

The current paradigm assesses transportation system efficiency based solely on vehicle traffic speeds, as well as on victimization metrics such as route level of service, travel time index, and its variants, such as the INRIX Congestion Scoreboard and the TomTom Traffic Index, which measure congestion severity or the reduction in vehicle speeds during peak hours. These interventions are effective for a short period or on a one-time basis. They do not offer optimal solutions (e.g., the number of people traveling during peak hours). They ignore the potential benefits of mode shifting or various open construction trends that reduce travel distances. It is important to use metrics that quantify congestion costs, such as annual per capita congestion delay, when designing functions. (Akele, G. A., Akele, M. U., 2018)

Identification of Congestion Measurement Metrics

Traffic congestion is characterized and measured in several ways. **Speed** is a key indicator, with slow speeds in urban areas often signifying congestion, while GPS data aids in real-time monitoring. **Travel time and delay** define congestion as a significant increase beyond free-flow conditions, with unacceptable levels varying by context. **Volume**, such as bridge crossings, can also serve as a simple congestion indicator. **Level of Service (LOS)**, like Michigan's LOS F when volume exceeds capacity, is another metric. From a **demand and capacity** perspective, congestion arises when traffic volume surpasses the infrastructure's ability to handle it efficiently, leading to reduced speed and predictability. **Cost-related** definitions highlight congestion as undesirable due to decreased mobility and increased travel expenses. Effective congestion measurement methodologies should be understandable, adaptable to changing patterns, mathematically sound and replicable with minimal data, and applicable across different transport modes and timeframes.

Measures and Methodologies

Various metrics quantify traffic congestion. **Speed-based measures** include the average travel rate, nominal peak-hour speeds, and the Speed Reduction Index, which compares peak and off-peak speeds. The Traffic Transmission Quality index (Q index) incorporates speed and speed changes. The Corridor Mobility Index (CMI) assesses a corridor's commuter capacity using traffic volume velocity. **Travel time** analysis contrasts peak and free-flow durations, with the Travel Rate Index focusing on the extra time needed due to congestion and the Buffer Index calculating the additional time for reliable on-time arrival. **Level of Service (LOS)**, adopted in HCM, uses the volume-capacity ratio to indicate operating conditions, with the Highway Congestion Index (ICV) measuring congestion based on vehicle-miles traveled per lane mile. The Lane Duration Mile Index (LDMI) quantifies the extent and duration of congestion. **Delay measures** define congestion as time exceeding free-flow or acceptable travel times, with researchers using volume-to-capacity ratios or specific speed thresholds to identify the onset of delay.

Data Collection Methods

Traffic congestion data is primarily collected using two methods: mobile single-probe vehicles and stationary fixed sensors. Fixed sensors, like inductive loops and magnetic sensors placed on roads, gather data on traffic volume and speed. Double-loop detectors can estimate traffic interference. Image-based methods, using CCTV and satellite images, analyze the rate of visual changes to assess congestion in real time. Probe vehicle techniques utilize vehicles equipped with GPS and other sensors to measure parameters like speed and location, employing prediction and localization for analysis.

Since real-time data for Kanpur was unavailable, information regarding traffic congestion was sourced from the Kanpur Metropolitan Region Development Authority (KMRDA) and the Kanpur Nagar Nigam (KNN) for data collected approximately two to three months prior. These authorities are responsible for the planning, development, and maintenance of road infrastructure within the Kanpur metropolitan area and the city of Kanpur, respectively, and their data provides insights into recent traffic patterns in a geographically proximate urban center.

Case Study: Kanpur

Introduction

Kanpur is one of the largest cities in the state of Uttar Pradesh and the main centre of economic and industrial activities. Formerly known as Manchester, it is currently the provincial capital. It is located along major national highways, such as Highways 12 and 25, the main Delhi-Howrah railway, and on the banks of the holy Ganges River. It is approximately 126 meters above sea level. (KMC, 2019) Kanpur is the second most densely populated city in Uttar Pradesh, after Lucknow, and its urban agglomeration is among the largest in Asia. It is a major rail and road hub, with a significant domestic flight network. The city is a major industrial centre and is famous for its fur trade, with several of the world's largest tanneries. The city centre is located northwest of a military camp (installation). Most of its trade continues further northwest. (KMC, 2019)

Traffic congestion limited online selection issues when Kanpur competed for a spot among 100 good cities. The public's response to the issue astonished the Union Ministry of Urban Development. Extraordinary efforts were made to develop a traffic plan in collaboration with the Kanpur Development Authority, leading experts, and various agencies. An intelligent traffic management system of Rs 170 million has been budgeted in the smart city strategy. Initially, it would cover 85 of the city's 177 junctions, with the remaining junctions to be added later. (Britannica)

Four major intersections in Kanpur (Jarib Chowki, Rama-Devi, Ghantaghar, and Bada Chowraha) were considered for the study. Methodology (Akeke, G.A. and Akeke, M.U. and Okafor, F.O. and Ezeokonkwo, J.C., 2018)

Traffic Volume Counts: Traffic volume counts are conducted at major intersections and critical junctions only during peak flow periods, as determined by a twelve-hour traffic volume count. Traffic volume is measured in units of vehicles per hour (PCU/h).

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(**Source:** Highway Capacity Manual (HCM) [1])

Results and Discussion

Traffic in the study area was surveyed for three days at each of the four intersections. Traffic data was collected by the NHAI (Vasant Vihar, Kanpur). The results are summarized in tables and graphs to illustrate the road trajectory in the market in the study area. An analysis of the field survey results is presented.

Traffic Flow Characteristics at the Major Intersections in Kanpur Metropolis.

	Jarib Chowki			Rama-Devi			Ghantaghar			Bada Chowraha		
Avg Weekday Hour Volume	1374.541667	1427.166667	1400.042	1064.375	1037.583333	1059.5	1642.25	1677.416667	1720.833333	1385.416667	1354.167	1429.167
AM Peak	2352	2374	2339	2033	2052	2022	2499	2552	2618	2361	2093	2401
Hour	7.129649277	6.930982132	6.961102	7.958505	8.240301984	7.951864087	6.340386665	6.339112723	6.338983051	7.10075188	6.44	7
PM Peak	2930	2882	2964	1903	1554	1960	4690	4767	4915	2474	3738	4145
Hour	8.881748462	8.414107205	8.821166	7.449599	6.240462613	7.708038383	11.89932511	11.84112475	11.90072639	7.440601504	11.50154	12.08455
Avg Hour (7AM-7PM)	26838	28019	27095	22003	21552	22075	31247	31816	32613	25686	25633	27849
	81.35439086	81.80252248	80.63748	86.13427	86.54726528	86.81374862	79.27893642	79.03025486	78.96610169	77.25112782	78.87077	81.19242
Avg Hour	32989	34252	33601	25545	24902	25428	39414	40258	41300	33250	32500	34300
24 Hour	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Table 1 shows the final summary of traffic flow characteristics of Kanpur road network with four (4) major intersections/crossings including normal 12-hour regular volumes, typical AM and PM peak hour volumes, average 24-hour volumes and various traffic variation factors considering 24-hour average totals. The results show that the 12-hour average regular flow at the busiest intersection/crossing accounts for only one-seventh of the total 24-hour flow. Data for this finding was collected and analyzed over three days at various intersections/crossings in the analysis (see Table 1).

Time	Jarib Chowki			Rama-Devi			Ghantaghar			Bada Chowraha		
0:00-1:00	50	55	49	56	62	56	197	225	231	173	130	219
1:00-2:00	66	65	57	43	40	42	307	314	322	160	221	192
2:00-3:00	79	75	80	33	32	34	198	201	207	113	163	75
3:00-4:00	83	73	84	43	43	39	78	117	124	67	163	89
4:00-5:00	126	155	109	64	60	56	95	137	161	409	78	137
5:00-6:00	211	216	202	112	113	102	528	539	553	602	436	185
6:00-7:00	257	223	255	276	261	257	749	765	785	635	618	411
7:00-8:00	1927	1925	1831	1591	1554	1551	2010	2053	2106	1975	1710	1804
8:00-9:00	2207	2216	2325	2148	2204	2080	4261	4251	4229	2677	3283	3519
9:00-10:00	2352	2374	2339	2033	2052	2022	2499	2552	2618	2361	2093	2401
10:00-11:00	2022	2124	2026	1824	1701	1808	2105	2150	2205	2188	1768	1790
11:00-12:00	1837	1857	1874	1768	1796	1841	2128	2174	2230	2008	1770	1838
12:00-13:00	1838	1991	1885	1701	1619	1772	2089	2134	2189	2075	1721	1749
13:00-14:00	2319	2596	2072	1709	1556	1714	2172	2242	2299	1975	1794	2054
14:00-15:00	1966	2494	2367	1709	1776	1719	2010	2053	2272	2008	1658	1783
15:00-16:00	2290	2377	2314	1778	1825	1597	2128	2174	2148	1839	1788	2129
16:00-17:00	2313	2367	2213	1908	1952	1966	2278	2327	2387	2035	1885	2167
17:00-18:00	2837	2816	2885	1931	1963	2045	2877	2939	3015	2071	2425	2470
18:00-19:00	2930	2882	2964	1903	1554	1960	4690	4767	4915	2474	3738	4145
19:00-20:00	2606	2552	2638	978	964	915	2806	2866	2941	1839	2314	2181
20:00-21:00	1316	1432	1595	874	663	817	1261	1288	1322	1350	1157	1173
21:00-22:00	978	1011	1034	531	589	501	1064	1087	1115	1037	878	1001
22:00-23:00	201	212	259	319	311	320	733	749	768	851	572	548
23:00-0:00	178	164	144	209	212	214	150	153	157	329	143	237
Total Vehicles	32989	34252	33601	25545	24902	25428	39414	40258	41300	33250	32500	34300

Table 2 takes the average of the three days. We find that the highest traffic, with 40,324 vehicles per day, is in Ghantaghar, followed by Jarib Chowki with 33,614 vehicles per day, followed by Bada Chowraha with 33,350 vehicles per day and Rama Devi with 25,292 vehicles per day, respectively.

	Average Traffic Flow Characteristics at the Major Intersections in Kanpur Metropolis.			
	Jarib Chowki	**Rama-Devi**	**Ghantaghar**	**Bada Chowraha**
Avg Weekday Hour Volume	1400.583333	1053.819444	1680.166667	1389.583333
AM Peak	2355	2035.666667	2556.333333	2285
Hour	7.007244586	8.050223557	6.339494146	6.846917293
PM Peak	2925.333333	1805.666667	4790.666667	3452.333333
Hour	8.705673901	7.132699915	11.88039208	10.34222936
Avg Hour (7AM-7PM)	27317.33333	21876.66667	31892	26389.33333
	81.26479812	86.49842892	79.09176432	79.10477229
Avg Hour	33614	25292	40324	33350
24 Hour	100%	100%	100%	100%

Tables 3, 4, 5 and 6 show the hourly distribution of traffic at the 4 main intersections of Kanpur during the 3 days.

	Hourly Traffic Distribution at Jarib Chowki Traffic Flow Characteristics at the Major Intersections in Knapur											
Time	Day 1				Day 2				Day 3			
	Vehcile No.	Percentage	Cum Freq	Cum Per	Vehcile No.	Percentage	Cum Freq	Cum Per	Vehcile No.	Percentage	Cum Freq	Cum Per
0:00-1:00	50	0.15	50	0.15	55	0.16	55	0.16	49	0.15	49	0.15
1:00-2:00	66	0.20	116	0.35	65	0.19	120	0.35	57	0.17	106	0.32
2:00-3:00	79	0.24	195	0.59	75	0.22	195	0.57	80	0.24	186	0.55
3:00-4:00	83	0.25	278	0.84	73	0.21	268	0.78	84	0.25	270	0.80
4:00-5:00	126	0.38	404	1.22	155	0.45	423	1.23	109	0.32	379	1.13
5:00-6:00	211	0.64	615	1.86	216	0.63	639	1.87	202	0.60	581	1.73
6:00-7:00	257	0.78	872	2.64	223	0.65	862	2.52	255	0.76	836	2.49
7:00-8:00	1927	5.84	2799	8.48	1925	5.62	2787	8.14	1831	5.45	2667	7.94
8:00-9:00	2207	6.69	5006	15.17	2216	6.47	5003	14.61	2325	6.92	4992	14.86
9:00-10:00	2352	7.13	7358	22.30	2374	6.93	7377	21.54	2339	6.96	7331	21.82
10:00-11:00	2022	6.13	9380	28.43	2124	6.20	9501	27.74	2026	6.03	9357	27.85
11:00-12:00	1837	5.57	11217	34.00	1857	5.42	11358	33.16	1874	5.58	11231	33.42
12:00-13:00	1838	5.57	13055	39.57	1991	5.81	13349	38.97	1885	5.61	13116	39.03
13:00-14:00	2319	7.03	15374	46.60	2596	7.58	15945	46.55	2072	6.17	15188	45.20
14:00-15:00	1966	5.96	17340	52.56	2494	7.28	18439	53.83	2367	7.04	17555	52.25
15:00-16:00	2290	6.94	19630	59.50	2377	6.94	20816	60.77	2314	6.89	19869	59.13
16:00-17:00	2313	7.01	21943	66.52	2367	6.91	23183	67.68	2213	6.59	22082	65.72
17:00-18:00	2837	8.60	24780	75.12	2816	8.22	25999	75.91	2885	8.59	24967	74.30
18:00-19:00	2930	8.88	27710	84.00	2882	8.41	28881	84.32	2964	8.82	27931	83.13
19:00-20:00	2606	7.90	30316	91.90	2552	7.45	31433	91.77	2638	7.85	30569	90.98
20:00-21:00	1316	3.99	31632	95.89	1432	4.18	32865	95.95	1595	4.75	32164	95.72
21:00-22:00	978	2.96	32610	98.85	1011	2.95	33876	98.90	1034	3.08	33198	98.80
22:00-23:00	201	0.61	32811	99.46	212	0.62	34088	99.52	259	0.77	33457	99.57
23:00-0:00	178	0.54	32989	100.00	164	0.48	34252	100.00	144	0.43	33601	100.00
	32989	100.00			34252	100.00			33601	100.00		

	Hourly Traffic Distribution at Rama Devi Traffic Flow Characteristics at the Major Intersections in Knapur											
Time	Day 1				Day 2				Day 3			
	Vehcile No.	Percentage	Cum Freq	Cum Per	Vehcile No.	Percentage	Cum Freq	Cum Per	Vehcile No.	Percentage	Cum Freq	Cum Per
0:00-1:00	56	0.22	56	0.22	62	0.25	62	0.25	56	0.22	56	0.22
1:00-2:00	43	0.17	99	0.39	40	0.16	102	0.41	42	0.17	98	0.39
2:00-3:00	33	0.13	132	0.52	32	0.13	134	0.54	34	0.13	132	0.52
3:00-4:00	43	0.17	175	0.69	43	0.17	177	0.71	39	0.15	171	0.67
4:00-5:00	64	0.25	239	0.94	60	0.24	237	0.95	56	0.22	227	0.89
5:00-6:00	112	0.44	351	1.37	113	0.45	350	1.41	102	0.40	329	1.29
6:00-7:00	276	1.08	627	2.45	261	1.05	611	2.45	257	1.01	586	2.30
7:00-8:00	1591	6.23	2218	8.68	1554	6.24	2165	8.69	1551	6.10	2137	8.40
8:00-9:00	2148	8.41	4366	17.09	2204	8.85	4369	17.54	2080	8.18	4217	16.58
9:00-10:00	2033	7.96	6399	25.05	2052	8.24	6421	25.79	2022	7.95	6239	24.54
10:00-11:00	1824	7.14	8223	32.20	1701	6.83	8122	32.62	1808	7.11	8047	31.65
11:00-12:00	1768	6.92	9991	39.12	1796	7.21	9918	39.83	1841	7.24	9888	38.89
12:00-13:00	1701	6.66	11692	45.78	1619	6.50	11537	46.33	1772	6.97	11660	45.85
13:00-14:00	1709	6.69	13401	52.47	1556	6.25	13093	52.58	1714	6.74	13374	52.60
14:00-15:00	1709	6.69	15110	59.16	1776	7.13	14869	59.71	1719	6.76	15093	59.36
15:00-16:00	1778	6.96	16888	66.12	1825	7.33	16694	67.04	1597	6.28	16690	65.64
16:00-17:00	1908	7.47	18796	73.59	1952	7.84	18646	74.88	1966	7.73	18656	73.37
17:00-18:00	1931	7.56	20727	81.15	1963	7.88	20609	82.76	2045	8.04	20701	81.41
18:00-19:00	1903	7.45	22630	88.60	1554	6.24	22163	89.00	1960	7.71	22661	89.12
19:00-20:00	978	3.83	23608	92.43	964	3.87	23127	92.87	915	3.60	23576	92.72
20:00-21:00	874	3.42	24482	95.85	663	2.66	23790	95.53	817	3.21	24393	95.93
21:00-22:00	531	2.08	25013	97.93	589	2.37	24379	97.90	501	1.97	24894	97.90
22:00-23:00	319	1.25	25332	99.18	311	1.25	24690	99.15	320	1.26	25214	99.16
23:00-0:00	209	0.82	25541	100.00	212	0.85	24902	100.00	214	0.84	25428	100.00
	25541	100.00			24902	100.00			25428	100.00		

	Hourly Traffic Distribution at Ghantaghar Traffic Flow Characteristics at the Major Intersections in Knapur											
Time	Day 1				Day 2				Day 3			
	Vehcile No.	Percentage	Cum Freq	Cum Per	Vehcile No.	Percentage	Cum Freq	Cum Per	Vehcile No.	Percentage	Cum Freq	Cum Per
0:00-1:00	197	0.50	197	0.50	225	0.56	225	0.56	231	0.56	231	0.56
1:00-2:00	307	0.78	504	1.28	314	0.78	539	1.34	322	0.78	553	1.34
2:00-3:00	198	0.50	702	1.78	201	0.50	740	1.84	207	0.50	760	1.84
3:00-4:00	78	0.20	780	1.98	117	0.29	857	2.13	124	0.30	884	2.14
4:00-5:00	95	0.24	875	2.22	137	0.34	994	2.47	161	0.39	1045	2.53
5:00-6:00	528	1.34	1403	3.56	539	1.34	1533	3.81	553	1.34	1598	3.87
6:00-7:00	749	1.90	2152	5.46	765	1.90	2298	5.71	785	1.90	2383	5.77
7:00-8:00	2010	5.10	4162	10.56	2053	5.10	4351	10.81	2106	5.10	4489	10.87
8:00-9:00	4261	10.81	8423	21.37	4251	10.56	8602	21.37	4229	10.24	8718	21.11
9:00-10:00	2499	6.34	10922	27.71	2552	6.34	11154	27.71	2618	6.34	11336	27.45
10:00-11:00	2105	5.34	13027	33.05	2150	5.34	13304	33.05	2205	5.34	13541	32.79
11:00-12:00	2128	5.40	15155	38.45	2174	5.40	15478	38.45	2230	5.40	15771	38.19
12:00-13:00	2089	5.30	17244	43.75	2134	5.30	17612	43.75	2189	5.30	17960	43.49
13:00-14:00	2172	5.51	19416	49.26	2242	5.57	19854	49.32	2299	5.57	20259	49.05
14:00-15:00	2010	5.10	21426	54.36	2053	5.10	21907	54.42	2272	5.50	22531	54.56
15:00-16:00	2128	5.40	23554	59.76	2174	5.40	24081	59.82	2148	5.20	24679	59.76
16:00-17:00	2278	5.78	25832	65.54	2327	5.78	26408	65.60	2387	5.78	27066	65.54
17:00-18:00	2877	7.30	28709	72.84	2939	7.30	29347	72.90	3015	7.30	30081	72.84
18:00-19:00	4690	11.90	33399	84.74	4767	11.84	34114	84.74	4915	11.90	34996	84.74
19:00-20:00	2806	7.12	36205	91.86	2866	7.12	36980	91.86	2941	7.12	37937	91.86
20:00-21:00	1261	3.20	37466	95.06	1288	3.20	38268	95.06	1322	3.20	39259	95.06
21:00-22:00	1064	2.70	38530	97.76	1087	2.70	39355	97.76	1115	2.70	40374	97.76
22:00-23:00	733	1.86	39263	99.62	749	1.86	40104	99.62	768	1.86	41142	99.62
23:00-0:00	150	0.38	39413	100.00	153	0.38	40257	100.00	157	0.38	41299	100.00
	39413	100.00			40257	100.00			41299	100.00		

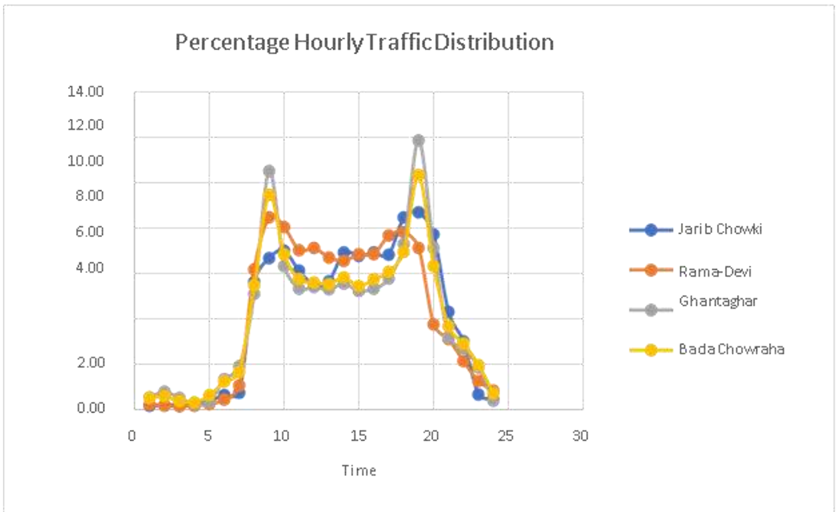
	33251	100.00			32506	100.00			34297	100.00		

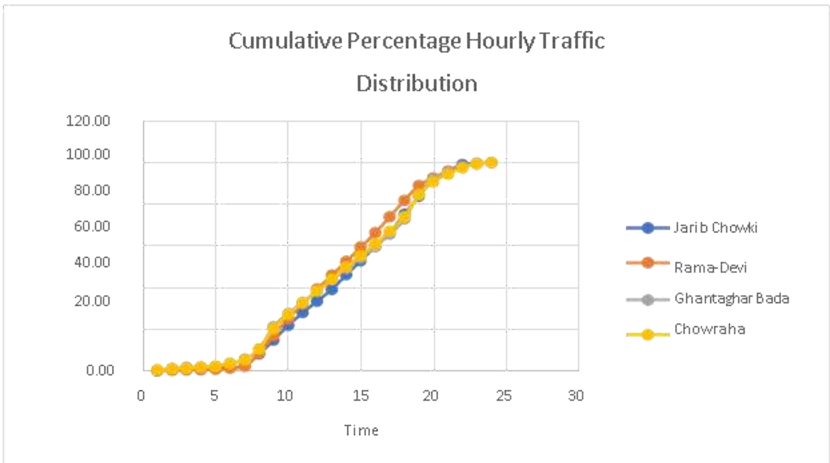
33614		25290		40323		33351	

Table 7 represents the hourly traffic summary at four major intersections in Kanpur. It shows the number of vehicles per hour, the percentage of vehicles per hour, and their cumulative number and percentage. This table will later be useful for calculating the traffic flow rate, which will allow measuring congestion at different intersections at different times. The road capacity at the different intersections is indicated.

Below are two scatter plots representing the percentage distribution of hourly traffic and the cumulative percentage distribution of hourly traffic at four major intersections in Kanpur.

The x-axis shows the time in 24-hour format, while the y-axis represents the percentage and cumulative percentage of traffic.





To measure congestion, the mobility index is used, which represents the capacity at various intersections per hour. The volume is divided by the capacity, and the mobility index is measured.

	Mobility Ratio			
Time	**Jarib Chowki**	**Rama-Devi**	**Ghantaghar**	**Bada Chowraha**
0:00-1:00	0.03	0.03	0.10	0.09
1:00-2:00	0.03	0.02	0.14	0.10
2:00-3:00	0.04	0.02	0.09	0.06
3:00-4:00	0.04	0.02	0.05	0.05
4:00-5:00	0.07	0.03	0.06	0.10
5:00-6:00	0.10	0.06	0.24	0.20
6:00-7:00	0.12	0.15	0.34	0.28
7:00-8:00	0.95	0.89	0.91	0.91
8:00-9:00	1.12	1.23	1.89	1.58
9:00-10:00	1.18	1.16	1.14	1.14
10:00-11:00	1.03	1.02	0.96	0.96
11:00-12:00	0.93	1.03	0.97	0.94
12:00-13:00	0.95	0.97	0.95	0.92
13:00-14:00	1.16	0.95	0.99	0.97
14:00-15:00	1.14	0.99	0.94	0.91
15:00-16:00	1.16	0.99	0.96	0.96
16:00-17:00	1.15	1.11	1.04	1.01
17:00-18:00	1.42	1.13	1.31	1.16
18:00-19:00	1.46	1.03	2.13	1.73
19:00-20:00	1.30	0.54	1.28	1.06
20:00-21:00	0.72	0.45	0.57	0.61
21:00-22:00	0.50	0.31	0.48	0.49
22:00-23:00	0.11	0.18	0.33	0.33
23:00-0:00	0.08	0.12	0.07	0.12
Capacity/hrs	2000	1750	2250	2000

The mobility index in black represents the absence of congestion. Green represents moderate congestion. Purple represents severe congestion. The mobility index in red represents severe congestion.

Observations:

1. The highest congestion level in Ghantaghar is 2.13. Being close to the Z Square mall, it attracts a lot of people at night.

2. At night, congestion increases from moderate to severe.

3. All intersections are congested during peak hours.

4. There is no congestion during off-peak hours.

Mitigation Measures

There are various measures to reduce congestion worldwide. To mitigate congestion in the city of Kanpur, we suggest some possible mitigation measures.

1. Congestion Pricing

This is a system that charges users of a transportation network during peak demand periods to reduce traffic congestion.

Mechanism: When supply is overused, users are charged for the negative consequences of peak demand. Countries: Singapore, Hong Kong, Sweden, United Kingdom

2. Lane Differentiation

To optimize the use of existing infrastructure and avoid the impact of congestion on public transport, lane differentiation is used.

Mechanisms: High-occupancy vehicle (HOV) lanes, high-occupancy vehicle (PTO) toll lanes, and lanes differentiated according to their performance characteristics.

Countries: United States, Netherlands, Australia, India

3. Road Widening

There are several intersections in the city where road widening is necessary. The congestion is due to a lack of road capacity.

4. Automated Traffic Signals

In this case, traditional traffic signals are combined with a series of sensors and artificial intelligence to intelligently plan and direct traffic signals, as well as the flow of vehicles and pedestrians.

5. Discourage private vehicles

The use of private vehicles should be discouraged and the use of public transportation promoted to reduce vehicle traffic and thus reduce congestion.

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