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Comparison of Ridership, CO_2 emissions, Travel Fare for Selected Routes in Bangalore and Tokyo Cities

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***Abstract*: The paper aims to compare the ridership, CO_2 emissions and the economic feasibility for the metro systems of Bangalore, India and Tokyo, Japan. The paper considers only two lines from each of the metro systems based on the similarities in line length. The ridership is compared using Californian Curve Model which is an assignment model. The CO_2 emissions are indirectly computed by first computing the electrical energy consumption using a simplified model. The economic feasibility is determined by computing the income spent per year on the metro using Per Capita Income and travel fare. The results demonstrate that Tokyo's metro is better than Bangalore's metro in all the aspects mentioned. Furthermore, the paper also recommends the improvements which can be implemented to directly or indirectly improve Bangalore's metro.**

***Keywords*: CO_2 emissions, travel fare, California curve model.**

1. Introduction

The increase in population in the past few decades has led to rapid urbanization often leading to unplanned development which in turn creates problems like traffic congestion, poor air quality etc. A well-developed public transport system is necessary to mitigate, if not eliminate the above problems. For example, Bangalore is an Indian metropolis with a population of more than 8 million residents and suffers from one of the worst traffic congestions in India as well as ranking among the top ten cities with the worst traffic congestion in the world during the year 2020. Although the metro system was constructed and opened in the year 2011 to mitigate the traffic congestion, the expected results were not reached as the city was still suffering from bad traffic congestions. Whereas, Tokyo is a Japanese metropolis with an estimated population of about 13 million for the year 2021. One would expect the city to suffer from a far worse traffic congestion but the presence of a well-developed and widely-utilized metro network mitigates the traffic issues. Moreover, there are benefits other than the reduction in traffic congestion such as lowering the overall carbon footprint, improving the living conditions, raising the land value around the metro stations among others.

2. Literature Review

A case study on Delhi's metro by G. Tiwari [1] was conducted on various aspects. One of the aspects included computing CO2 emissions by a model utilizing the electrical energy consumption. The electrical energy consumption utilized included the consumption by air-conditioning, lighting, rolling stock and the stations. Another model developed by Jyh-Cherng Jong [2] computes the electrical energy consumption through the integration of input power over time. The energy estimation model included the energy used by traction motors, energy consumption by auxiliary equipment and the energy produced by regenerative braking. An error reduction algorithm was also introduced to reduce the error in estimation. Franklin Gbologah [3] developed a calibrated model to estimate the emissions using five modules: data reporting (user input data), instantaneous rolling tractive effort, starting tractive effort, power recovery (regenerative braking) and emission analysis. Jinghui Wang [4] proposed a framework model which estimated energy consumption in two parts: energy consumed during traction and energy produced/regenerated during regenerative braking. The average energy consumed is estimated by summing the data from the above model and dividing it by the trip length. Xin Yang [5] mentions that timetable optimization and energy-efficient driving can have major contributions to the reduction in energy consumption. Synchronizing the braking phase and accelerating phase of two different trains through timetable optimization, energy regenerated through regenerative braking can be reutilized, as the regenerated energy will be lost if the necessary equipment is not provided to store the energy. Kevin B. Modi [6] presents an overview of the travel demand modelling for transportation planning and explains about the four stages in modelling. The paper also presents different models for travel demand modelling along with the advantages and limitations.

3. Objectives

Comparison of ridership for the selected metro routes.

- Computing and comparing the CO_2 emissions per passenger for the selected metro routes.
- Comparison of economic feasibility using travel fare and Per Capita Income for the selected metro routes.

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4. Methodology

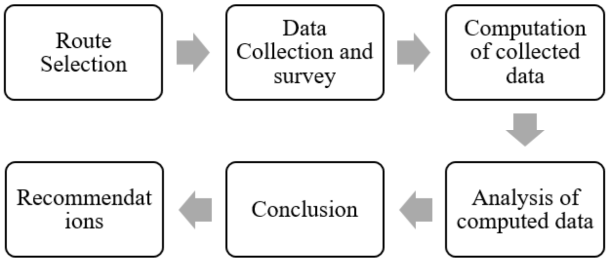

Fig. 1. Methodology flowchart

A. Route selection and data

The metro routes were selected based on the similarities in line length. The line length was collected through official sources and validated by plotting on Google maps. Both the travel time and travel fare for Tokyo's metro was collected through an official source while in the case of Bangalore's metro, the above data was collected through field survey. The time taken to travel by private vehicle was collected using Google Maps.

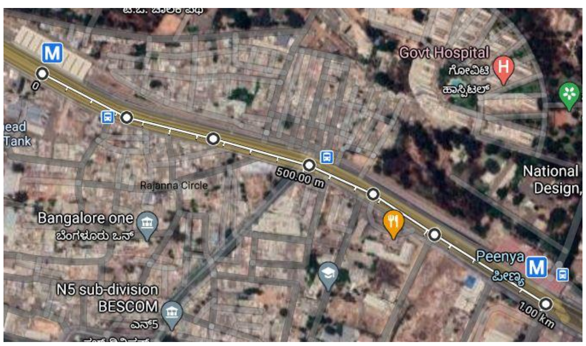

Fig. 2. Validating line length by plotting on Google Maps

B. Californian Curve Model

The Californian Curve Model is an empirically derived relationship that shows the proportion of traffic that is likely to be diverted from the old facility to the new facility based on the time saved and the distance saved between the two routes. Using this model, the percentage of traffic diverted for each route was found out, thereby determining the ridership levels in the selected lines. It is considered that the old facility are roads (private vehicles) and the new facility are the metro lines and the metro stations. However, there are limitations to this model. They are as follows.

- Only two routes can be considered at a time.
- The travel behaviour of an individual is not considered.
- The capacities of the facilities are not considered.

a) *California Curves Model:* In the California curves model, travel time saved and distance saved for two routes can be assigned the traffic.

$$\%\ traffic\ diverted\ (P) = 50 + \frac{50 * (d + 0.5t)}{\left[(d - 0.5t)^2 + 4.5\right]^{0.5}} \quad (28)$$

Where, d = distance saved on the new route (miles)
T = travel time saved (minutes)

Note 1: The percentage of traffic diverted was computed for Station 1 to Station N, i.e., Station 1 to Station 2, Station 1 to Station 3 and so on.

Note 2: After computation, it was noted that some values were either above 100% or below 0%. This cannot be physically possible and this issue is likely due to the limitations of the model. Hence in such cases, it was assumed that the maximum and minimum values are 90% and 10% respectively.

C. CO_2 Emission Estimation

Since the selected metro routes are electrically powered, the emissions cannot be directly computed. Therefore, a simplified model was utilized to compute the CO_2 emissions in terms of kilograms per passenger. This model is a modified version of the model given by G. Tiwari [1]. The modified model is given below.

$$CO_2 \text{ emissions in kilograms per passenger} = \frac{P * e * T}{C}$$

where,

P is the maximum power output in kW

e is the CO_2 emissions in kg per kWh

C is the total seating capacity of the rolling stock

T is the travel time from one station to another station in hours

Note: The graphs were represented as CO_2 emissions in kilograms per passenger versus distance in kilometer because unlike travel time which can vary, distance remains fixed.

D. Economic Feasibility

The percentage of income spent per year on travelling by metro, which is the ratio between the income spent on travelling by metro and the Per Capita Income (PCI), was used to determine the economic feasibility of the selected routes. Since PCI is the ratio between Gross Domestic Product (GDP) and the population, the GDP and the population have to be first estimated for a particular year, in this case, only the GDP was to be estimated for the year 2021 since the population estimate was already available. The GDP estimations were made using the MATLAB software and the following graphs show the estimation.

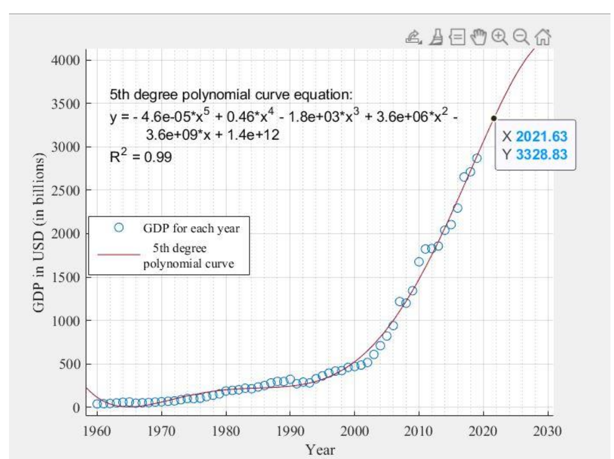

Fig. 3. Graphical estimation of GDP of India (in USD)

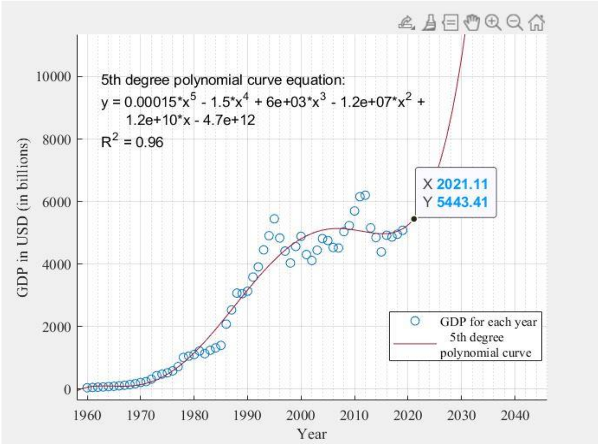

Fig. 4. Graphical estimation of GDP of Japan (in USD)

Before determining the economic feasibility, assumptions were made. It was assumed that the travel made by all the users was origin-destination-origin. For example; the user starts from home, travels to work in the morning and travels back home in the evening. Hence the travel fare would have to be twice the price.

Note: The fare prices were converted from their respective currencies to US Dollars (USD) for ease of comparison. As of March 2021, the conversion rate for the respective currencies is as follows.

- 1 INR = 0.014 USD
- 1 JPY = 0.0092 USD

5. Data Analysis

A. Californian Curve Model

Bangalore's Green Line: The percentage of traffic diverted was all above 50% due to the large amount of time saved by using the metro.

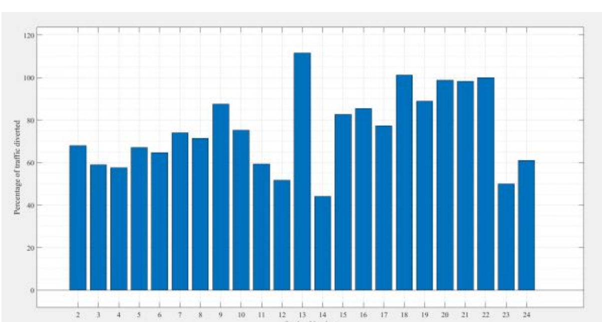

Fig. 5. Bar graph representing the percentage of traffic diverted when considering between Station 1 and Station N for Bangalore's Green Line

Bangalore's Purple Line: The percentage of traffic diverted was above 50% for half of the total number of stations while the rest were below 0%. Initially, both the distance and time saved by using the metro was high but was later overshadowed in both distance and time saved by using a private vehicle.

Tokyo's Hibiya (Silver) Line: The percentage of traffic diverted in most cases was above 20% with a few below 0% and some above 100%. In most cases, there was not much distance saved by using the metro. However, cases where time was saved by using the metro, showed better traffic diversion.

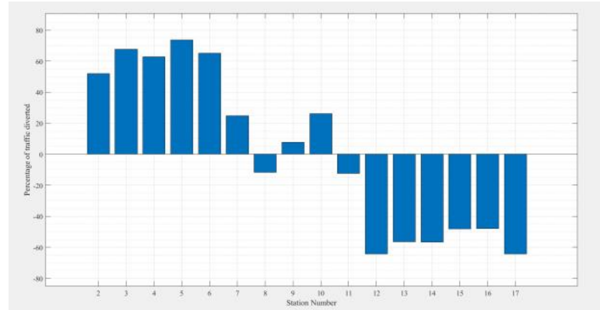

Fig. 6. Bar graph representing the percentage of traffic diverted when considering between Station 1 and Station N for Bangalore's Purple Line

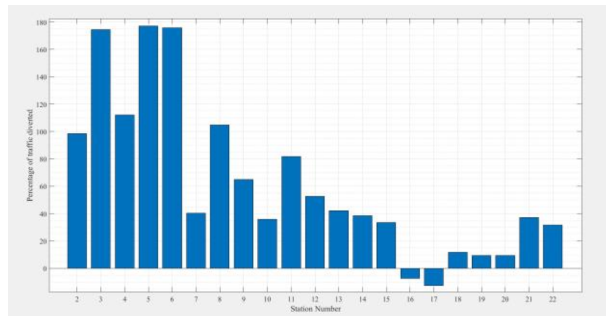

Fig. 7. Bar graph representing the percentage of traffic diverted when considering between Station 1 and Station N for Tokyo's Hibiya (Silver) Line

Tokyo's Namboku (Teal) Line: The percentage of traffic diverted was all above 50% due to a large amount of time saved by using the metro. Some cases showed better traffic diversion than others since in such cases, both time and distance were saved by using the metro.

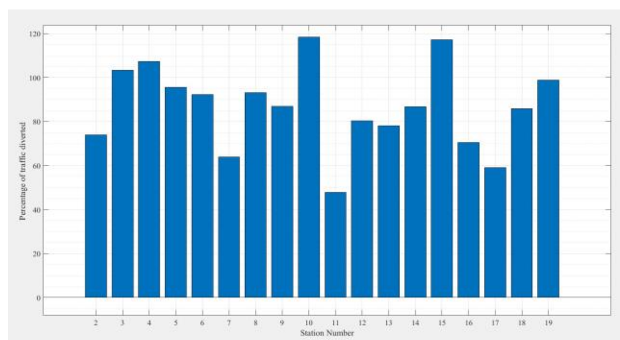

Fig. 8. Bar graph representing the percentage of traffic diverted when considering between Station 1 and Station N for Tokyo's Namboku (Teal) Line

B. CO_2 Emission Estimation

Table 1
Computation of CO_2 emissions in kilograms per passenger-hour at different levels of passenger loading

CO2 emissions kg per passenger-hour			City and Country
50% capacity	75% capacity	100% capacity	
26.27	17.51	13.13	Bangalore, India
6.90	4.60	3.45	Tokyo, Japan

The table given below present the CO_2 emissions in kilograms per passenger at different levels of passenger loading.

Table 2
Tabulated results for CO_2 emissions in kilograms per passenger for Bangalore's Green Line

Distance in km	Emissions in kg per passenger @50% capacity	Emissions in kg per passenger @75% capacity	Emissions in kg per passenger @100% capacity
1.4	0.60	0.40	0.30
2.4	1.22	0.81	0.61
3.1	1.81	1.21	0.90
4	2.39	1.60	1.20
5	3.04	2.02	1.52
6.1	3.62	2.41	1.81
7.2	4.37	2.91	2.19
8.2	4.95	3.30	2.48
9.1	5.63	3.75	2.81
10.1	6.14	4.10	3.07
10.8	6.93	4.62	3.47
12	7.81	5.21	3.91
13.6	8.39	5.59	4.20
14.6	8.85	5.90	4.43
15.4	9.52	6.35	4.76
16.5	10.25	6.83	5.13
17.5	10.78	7.18	5.39
18.4	11.29	7.52	5.64
19.4	11.81	7.87	5.91
20.2	12.72	8.48	6.36
21.6	13.25	8.83	6.62
22.5	13.92	9.28	6.96
23.9	14.58	9.72	7.29

Table 3
Tabulated results for CO_2 emissions in kilograms per passenger for Bangalore's Purple Line

Distance in km	Emissions in kg per passenger @50% capacity	Emissions in kg per passenger @75% capacity	Emissions in kg per passenger @100% capacity
1.1	0.89	0.59	0.45
2.4	1.79	1.20	0.90
3.4	2.57	1.71	1.28
4.5	3.41	2.27	1.70
5.6	4.33	2.88	2.16
6.8	5.19	3.46	2.60
7.5	5.76	3.84	2.88
8.8	6.54	4.36	3.27
9.9	7.21	4.81	3.61
10.5	7.76	5.17	3.88
11.8	8.80	5.87	4.40
12.9	9.46	6.30	4.73
14.1	10.13	6.76	5.07
15.5	11.18	7.46	5.59
16.8	12.37	8.25	6.19
17.8	13.30	8.87	6.65

Table 4
Tabulated results for CO_2 emissions in kilograms per passenger for Tokyo's Hibiya (Silver) Line

Distance in km	Emissions in kg per passenger @50% capacity	Emissions in kg per passenger @75% capacity	Emissions in kg per passenger @100% capacity
1	0.35	0.23	0.17
2.5	0.58	0.38	0.29
4.2	0.92	0.61	0.46
5.7	1.38	0.92	0.69
6.5	1.61	1.07	0.81
7	1.84	1.23	0.92
8.2	2.07	1.38	1.04
8.6	2.30	1.53	1.15
9	2.42	1.61	1.21
9.6	2.65	1.76	1.32
10.6	2.88	1.92	1.44
11.1	3.11	2.07	1.55
12	3.34	2.22	1.67
12.6	3.57	2.38	1.78
13.5	3.80	2.53	1.90
14.5	3.91	2.61	1.96
15	4.14	2.76	2.07
16.2	4.37	2.92	2.19
17.4	4.60	3.07	2.30
18.2	4.83	3.22	2.42
20.3	5.18	3.45	2.59

Table 5
Tabulated results for CO_2 emissions in kilograms per passenger for Tokyo's Namboku (Teal) Line

Distance in km	Emissions in kg per passenger @50% capacity	Emissions in kg per passenger @75% capacity	Emissions in kg per passenger @100% capacity
1.3	0.23	0.15	0.12
2.3	0.46	0.31	0.23
3.6	0.81	0.54	0.40
4.8	1.04	0.69	0.52
5.7	1.27	0.84	0.63
6.6	1.50	1.00	0.75
7.9	1.73	1.15	0.86
8.9	1.96	1.30	0.98
10	2.19	1.46	1.09
11.4	2.42	1.61	1.21
12.7	2.76	1.84	1.38
13.6	2.99	1.99	1.50
15	3.22	2.15	1.61
16.4	3.45	2.30	1.73
17.4	3.68	2.45	1.84
18.6	4.03	2.69	2.01
20.2	4.26	2.84	2.13
21.3	4.49	2.99	2.24

Table 6
Tabulated data and results for the percentage of income spent per year on Bangalore's Metro

	Travel Fare	Number of months travelled: 3 months	6 months	9 months	12 months
Currency in INR	9.5	1710	3420	5130	6935
	20.9	3762	7524	11286	15257
	33.25	5985	11970	17955	24272.5
	42.75	7695	15390	23085	31207.5

INR converted to USD prices			
23.94	47.88	71.82	97.09
52.67	105.34	158.00	213.60
83.79	167.58	251.37	339.82
107.73	215.46	323.19	436.91

PCI 2021 (USD)
2388.98

% expenditure spent per year on metro			
1.00	2.00	3.01	4.06
2.20	4.41	6.61	8.94
3.51	7.01	10.52	14.22
4.51	9.02	13.53	18.29

PCI 2021 in USD = 2388.98

Each matrix in one table corresponds to the same matrix in another table

Table 7
Tabulated data and results for the percentage of income spent per year on Tokyo's Metro

	Travel Fare	Number of months travelled: 3 months	6 months	9 months	12 months
Currency in JPY	170	30600	61200	91800	124100
	200	36000	72000	108000	146000
	250	45000	90000	135000	182500
	290	52200	104400	156600	211700

JPY converted to USD prices			
281.52	563.04	844.56	1141.72
331.2	662.4	993.6	1343.2
414	828	1242	1679
480.24	960.48	1440.72	1947.64

PCI 2021 (USD)
43449.95

% expenditure spent per year on metro			
0.65	1.30	1.94	2.63
0.76	1.52	2.29	3.09
0.95	1.91	2.86	3.86
1.11	2.21	3.32	4.48

PCI 2021 in USD = 43449.95

Each matrix in one table corresponds to the same matrix in another table

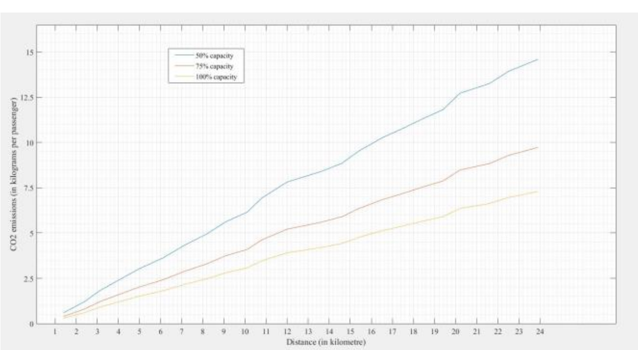

Fig. 9. Graph representing CO_2 emissions in kilograms per passenger at different levels of passenger loading for Bangalore's Green Line

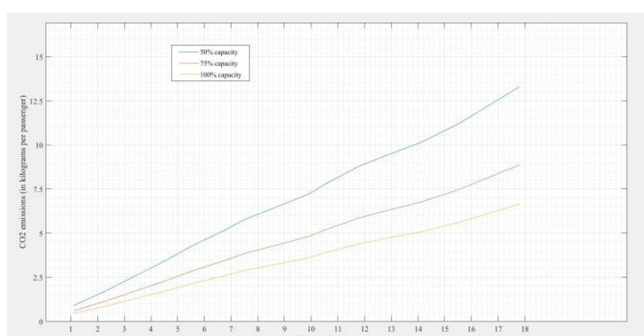

Fig. 10. Graph representing CO_2 emissions in kilograms per passenger at different levels of passenger loading for Bangalore's Purple Line

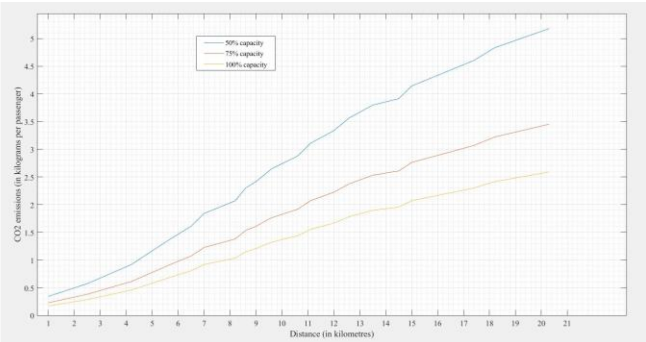

Fig. 11. Graph representing CO_2 emissions in kilograms per passenger at different levels of passenger loading for Tokyo's Hibiya (Silver) Line

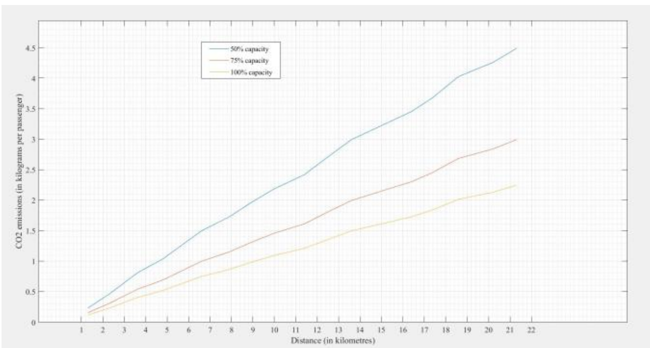

Fig. 12. Graph representing CO_2 emissions in kilograms per passenger at different levels of passenger loading for Tokyo's Namboku (Teal) Line

C. *Economic Feasibility*

The table 6 and table 7 presents the percentage of income spent per year for different ranges of travel fare and months travelled.

Bangalore:
Minimum yearly expenditure: 1.00%
Maximum yearly expenditure: 18.29%
Tokyo:
Minimum yearly expenditure: 0.65%
Maximum yearly expenditure: 4.48%

6. Conclusion

A. *Ridership*

Due to the drawbacks of the Californian Curve Model, the reasons for the ridership difference for the selected metro routes could not be precisely determined. However, general reasons can be drawn that can explain the lower ridership levels in Bangalore's metro. The reasons include;

- Tokyo has a much denser metro network compared to Bangalore. Interconnectivity between different metro lines or modes of transport significantly improves ridership.
- Tokyo has a much higher population and population density than Bangalore.
- Bangalore lacks Non-Motorized Transport Infrastructure (NMT) in most locations. Non-Motorized Transport (NMT) such as walkways, provide a safer route to a metro station.

B. *CO_2 emissions*

According to the computed data and graphs, it is clear that Bangalore metro's CO_2 emission is much than Tokyo metro's CO2 emissions. The reasons to the above conclusion are as follows.

- The CO_2 emissions per kilowatt for Japan was much lower than the CO_2 emissions per kilowatt for India in the year 2010. The situation may or may not be different in the year 2021.
- The power consumption for Bangalore metro's rolling stock is much higher than the power consumption of Tokyo metro's rolling stock.
- The seating capacity for Tokyo's rolling stock is slightly higher than Bangalore's rolling stock.

C. *Travel Fare*

The computed data shows that users of Bangalore's metro spend a maximum of 18.29% and a minimum of 1% of their annual income while the users of Tokyo's metro spend a maximum of 4.48% and a minimum of 0.65% of their annual income. While there is little difference in the lower ranges of yearly expenditure, the difference becomes very large at higher ranges of yearly expenditure. Although the travel fares for Tokyo's metro is higher, the yearly expenditure is higher for the users of Bangalore's metro due to the vast differences in Per Capita Income between India and Japan. Since the Per Capita Income only represents the average income of the entire population, the results should only be taken at face value.

7. Recommendations

- Undertaking campaigns to encourage people to utilize the metro system improves the ridership and in turn the revenue as well.
- A well-maintained network of Non-Motorized Transport infrastructure indirectly improves the ridership of the metro system by providing users a safer route to travel to the metro station.
- Offering discounts and concessions for metro tickets to certain categories of users such as students or senior citizens, help encourage said users to utilize the metro system, directly improving the ridership.
- In an urban scenario, the distance between metro stations can be less and there would often be sharp turns at certain sections. Due to these conditions, the metro train may not achieve the maximum speed most of the time. Hence, there is no necessity to deploy metro trains that achieve high speeds as they consume more electric power. This helps in reducing the indirect emissions as well as lowering the overall construction/maintenance costs.
- Improving the frequency between consecutive metro trains can potentially encourage people to utilize the metro system. The users can reach their intended destination faster, if they spend less time waiting for the metro train to arrive.
- Construction of green power in the local area, for example installing solar panels on the roof of the metro station, can

supplement the power supply for the metro system, potentially lowering the indirect emissions.

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