Impact Assessment of Introducing High Speed Rail on CO2 Emissions in India

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High Speed Rail (HSR) plays a significant role in economic urbanization and environmental impacts. India is also debating on the importance and impacts of HSR on climate. HSR is already operational in several countries today and a total of 12 HSR corridors are already planned in India, of which the construction of the Mumbai – Ahmedabad corridor is already underway. Even though there are several studies in literature in the context of various countries related to the impact of HSR on CO2 emissions, however such studies are very limited in Indian context. Keeping in mind that passenger travel is a major human activity contributing to CO2 emissions, the prime objective of this research is to study the impacts of HSR on CO2 emissions in Indian corridors. Hence a study of the Bengaluru – New Delhi corridor is taken. The hypothesis of the study is that introduction of HSR between Bengaluru – New Delhi will reduce CO2 emissions. Revealed Preference and Stated Preference survey was conducted using interview method for the purpose of data collection. Percentage shift of passengers from air travel to HSR was calculated. Thereafter the percentage reduction in CO2 emissions was calculated using emission factors from literature. It was found that there is a percentage reduction in CO2 emissions for all HSR options, and more so for the HSR option with night journey (with speed of 200 kmph) and moderate fare levels equivalent to the Rajdhani Express 2nd AC fares and that of a half day or night journey (with speed of 350 kmph) with fares equivalent to that of the Rajdhani 1st AC fare. The study suggests different possible options to introduce HSR in India that can reduce CO2 emissions from passenger travel and can help the Indian Government with some policy decision support.

Keywords: High Speed Rail, CO2 emissions, Climate, passenger travel, India, air travel, HSR.

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1 Introduction

Every year an increase in travel by human beings is witnessed through various modes of transport like aeroplanes, buses, cars, trains etc. However, this trend saw a significant dip in the year 2020 due to the lockdowns and other travel restrictions imposed by countries due to the COVID – 19 pandemic. But since then, travel has once again been on the rise. With the increase in travel, there is also an increase in the emissions of greenhouse gases like CO_2, but we cannot just ask people to just stop travelling. Air travel contributes approximately 1% of CO_2 emissions in India (source: https://ourworldindata.org/co2/country/india), but because these greenhouse gases are emitted at higher altitudes, the emissions caused by the aviation sector are far more harmful to the environment than any other mediums of transport. Hence an eco-friendlier alternative is required in India to rival with the aviation sector for long distance travels. This is where HSR can act as the perfect alternative to air travel.

HSR can facilitate significant economic urbanization and environmental impacts. When we compare rail to air transport, the railways are seen as a more sustainable alternative as the number of passengers carried by railway at a time is far greater than air transportation. It is also an eco-friendlier alternative than air transportation as it runs on electricity, provided the electricity is produced by clean and renewable sources of energy. (Åkerman, 2011) stated that HSR has a potential to attract intercity travellers from the air and private car, and reduce direct emissions of greenhouse gases from vehicle propulsion. HSR is already operational in several European and Asian countries today and a total of 12 HSR corridors are already planned in India (Figure 1), of which the construction of the Mumbai – Ahmedabad corridor is already underway. Even though there are several studies in literature in the context of various countries related to the impact of introducing HSR on CO_2 emissions, however such studies are very limited in Indian context.

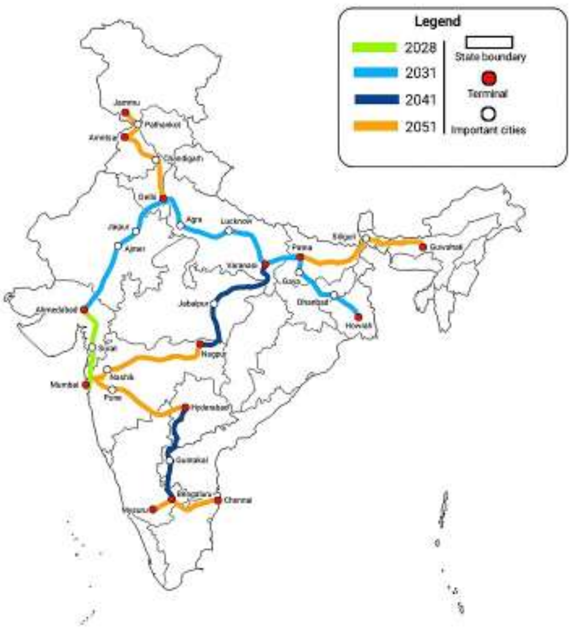

Figure 1. National Rail Plan's (NRP) proposed routes of HSR corridors (source: Wikipedia)

As of 2021, the fastest train of India is Vande Bharat Express which has a top speed of 180 km/hr (110 mph) which it attained during a trial run. The fastest operating train is Gatimaan Express with a top operating speed of 160 km/hr (99 mph) (source: Wikipedia). An HSR by definition is a passenger train that travels at 250 Km/hr or more on a new track or 200Km/hr on an upgraded track. The Mumbai – Ahmedabad HSR corridor of length 508 Km will have a top operational speed of 320 Km/hr along the western coast (source: The Hindu). The corridor will use Standard Gauge line and will be built with Japanese Shinkansen technology. For the purpose of current study, an HSR corridor connecting Bengaluru with New Delhi was considered. And a Revealed and Stated Preference survey was conducted via interview method to understand the traveler's preferred choice of travel and to calculate the percentage change in CO_2 emissions. The hypothesis chosen for current work is, "The introduction of HSR between Bengaluru – New Delhi will reduce CO_2 emissions".

2 Literature Review

Studies similar to this have been performed earlier in different parts of the world but not many have been conducted in an Indian context. (Dalkic et.al, 2017) performed their study on the existing HSR corridors in Turkey connecting the cities of Ankara, Istanbul, Konya, Eskisehir, Izmir and Bursa. In their study, they determined

- the current emissions of the HSR lines
- the estimated emissions from the alternative modes expected to be used in No-HSR situation, as stated in a HSR user survey, and the
- difference in emissions as the HSR reduction performance.

It was found that HSR caused a total reduction of 24.3 $ktCO_2$ currently on two study corridors and may even result in a reduction of 452.7 $ktCO_2$ in 2023. The CO2 emissions reduction potential of future HSR services can be higher if a) new HSR lines can create a network effect along the main corridor and b) supplementary policies can be developed to generate high HSR demand that would be shifted from car, and even air, on the longer routes.

(Raturi and Verma, 2013) performed a study in the Indian perspective where a case study of the Bengaluru – Mysore corridor was taken. For the purpose of data collection, revealed preference and Stated preference survey was conducted. A Discrete Choice Model was formed for calculating the model shift and market share of each mode of transport using the data collected. Sensitivity analysis was also performed to distinguish the changes in travel behaviour of the commuters based on socio - economic parameters such as gender, income, age etc. It was found that around 33.5% of the respondents were willing to shift towards HSR, of which 34.53% of bus users, 32.37% of train and 33.76% of private vehicle users said that they were willing to shift to HSR.

(Åkerman, 2011) used a proposed HSR track in Sweden by the name of Europabanan for his study. He used scenarios such as future developments in vehicular technology, bio-fuels, mix of electricity supply and transport volumes and life cycle assessments. Emissions consisting of greenhouse gases were considered to be the biggest impact category, but use of energy was also examined. The reductions in life – cycle emissions were found to be 550,000 tons of CO2-equivalents per annum by 2025/2030 of which around 60% of this came from a transition from truck to rail freight and 40% from a shift from air and road travel to HSR travel. It was also said that a significant share of emissions due to construction of the new HSR lines could be compensated through the decrease in the need for building and maintaining roads and airports, and for manufacturing personal vehicles.

(Jiang et.al, 2021) performed a review of existing papers on the impact on CO_2 emissions of High-Speed Rail projects due to its interactions with air transport, road and regular – speed rail. They briefly classified the studies into three levels, the first level focusing on comparing the emissions between HSR and the other modes of transport, the second on the impact on CO_2 emissions due to traffic adjustments caused by HSR, and the third on the life cycle assessment (LCA). They concluded that there are still limited studies in literature and that even though some studies already exist, many key factors and mechanisms have not been well considered. It was also found that a major imbalance exists between the studies of different modes of transports.

The next section discusses the proposed methodology of the work.

3 Proposed Methodology

The proposed methodology (Figure 2) consists of 3 phases, with the first being the Data Collection phase which comprises of the formulation of the objectives of the study and the collection of primary data through Revealed and Stated Preference survey. The second phase is the Data Analysis phase where the data collected from each of the 6 proposed HSR scenarios was analyzed to calculate the percentage shift to HSR and the percentage reduction in CO_2 emissions and the final phase is where the conclusions from the study were drawn and some suggestions on the implementation of HSR were formed.

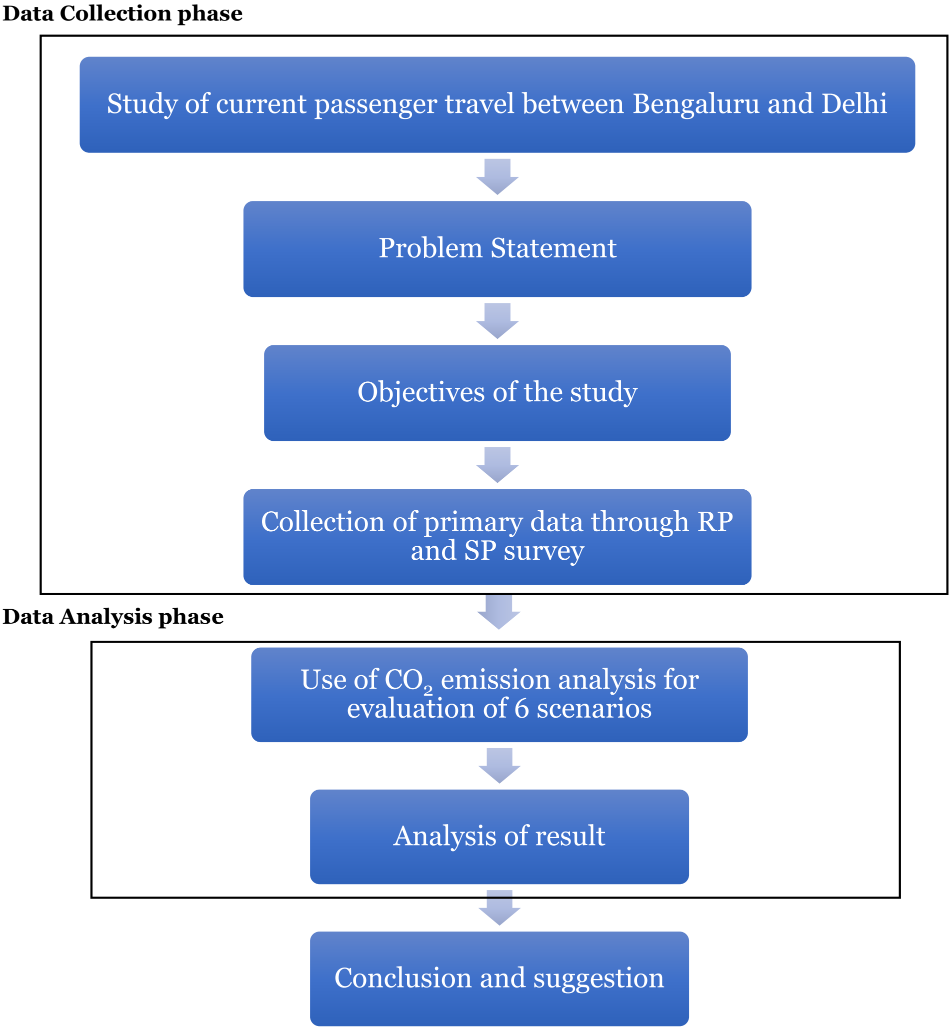

Figure 2. Flow chart depicting the methodology (source: author)

4 Data Collection phase

This phase includes the collection of data to be used for the Data Analysis phase. As mentioned earlier, primary data was collected using Revealed Preference and Stated Preference survey by taking personal interviews with respondents. 46 responses were collected from people who travel in economy class by air between Bengaluru and New Delhi. The Revealed Preference data consisted of personal information of the respondents such as their name, age, occupation, gender and the purpose of their last journey to and from New Delhi and the Stated Preference data consisted of the user preference of the six proposed HSR scenarios (B1 – B6) as shown in Table 1 vs the option of air travel (A).

Secondary data was collected from various other sources such as research papers, books, internet sources etc.

Table 1. The six proposed HSR scenarios with their respective speeds, travel time and fares

Option	HSR Choice
B1	200 Km/hr, 12 hours (overnight journey), ₹4500 (Rajdhani 2nd AC)
B2	200 Km/hr, 12 hours (overnight journey), ₹6500 (Rajdhani 1st AC)
B3	300 Km/hr, 8 hours (Late night departure and early morning arrival), ₹6500 (Rajdhani 1st AC)
B4	300 Km/hr, 8 hours (Late night departure and early morning arrival), ₹8000 (2/3rd of air fare)
B5	350 Km/hr, 6.5 hours (Half Day or night journey), ₹6500 (Rajdhani 1st AC)
B6	350 Km/hr, 6.5 hours (Half Day or night journey), ₹8000 (2/3rd of air fare)

5 Data Analysis phase

For the purpose of data analysis, MS – Excel was used. The data obtained from the Stated Preference survey was coded into an excel sheet in binary form, with air travel coded as "0" and the HSR alternative as "1". Using the responses collected, the percentage shift from air travel to the HSR alternative was calculated. The results of these calculations are shown in Figure 3.

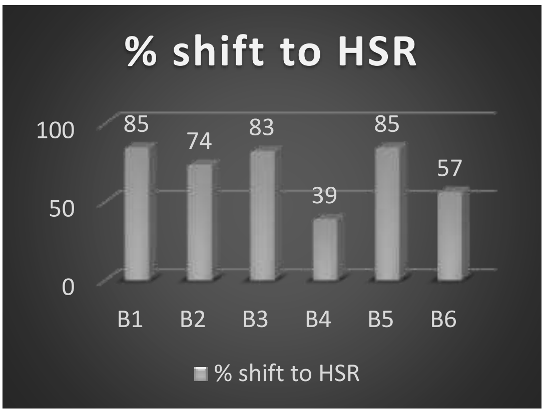

Figure 3. Percentage shift to HSR (source: author)

Next, using the result obtained from the above calculation, the annual passenger traffic of air and HSR after the implementation of HSR. For this purpose, the annual passenger traffic by air before the implementation of HSR (x) is taken as 374304 (Kodanda and Verma, 2011). The annual passenger traffic of HSR after the implementation of HSR (y) was calculated by finding the product of x and the percentage shift to HSR in each of the six scenarios. The annual passenger traffic of air transport after the implementation of HSR was found out by taking the difference between x and y. Table 2 shows the result of these calculations.

Table 2: Annual passenger traffic before and after the implementation of HSR

Sl.No.	HSR Option	Annual Passenger traffic before HSR is implemented		Annual Passenger traffic after HSR is implemented	
		AIR	HSR	AIR	HSR
B1	200 kmph, 12 hrs, Rs.4500	374304	0	56959	317345
B2	200 kmph, 12 hrs, Rs.6500	374304	0	97645	276659
B3	300 kmph, 8 hrs, Rs.6500	374304	0	65096	309208
B4	300 kmph, 8 hrs, Rs.8000	374304	0	227837	146467
B5	350 kmph, 6.5 hrs, Rs.6500	374304	0	56959	317345
B6	350 kmph, 6.5 hrs, Rs.8000	374304	0	162741	211563

The annual CO_2 emission before the implementation of HSR was then calculated using

$$z = x \times ER \times d \qquad (1)$$

where z is the annual CO_2 emission before the implementation of HSR, ER is the CO_2 emission rate of air transport which is 64.7 g/passenger – Km (Raturi and Verma, 2013) (Jardine, 2009) and d is the aerial distance between Bengaluru and New Delhi (1709 Km) (source: www.makemytrip.com). The annual CO_2 emission after the implementation of HSR was calculated by taking the sum of the emissions by air and HSR. The CO_2 emission by air is calculated using *(1)* where x is the annual passenger traffic by air after the implementation of HSR, ER is the CO_2 emission rate of air transport and d is the aerial distance between Bengaluru and New Delhi. The CO_2 emissions by HSR is also calculated using *(1)* where x is the annual passenger traffic by HSR, ER is the CO_2 emission rate of HSR which is 29.5 g/passenger – Km (Raturi and Verma, 2013) (Jardine, 2009) and d is the rail route length between Bengaluru and New Delhi (2365 Km) (source: www.indianrail.gov.in).

The net change in annual CO_2 emission was then calculated by taking the difference between the annual CO_2 emissions before and after the implementation of HSR and finally the percentage reduction of CO_2 emissions was found using

$$z = \frac{x}{y} \times 100 \qquad (2)$$

Where x is the net change in annual CO_2 emission and y is the annual CO_2 emission before the implementation of HSR. The findings of the calculations have been given in Table 3.

Table 3. Net change in annual CO_2 emission after HSR implementation and the percentage reduction in CO_2 emission

Sl.No.	HSR Option	Annual CO_2 emission before HSR implementation	Annual CO_2 emission after HSR implementation	Net change in annual CO_2 emission	% Reduction in CO_2 emission
B1	200 kmph, 12 hrs, Rs.4500	41387654179	28438467342	12949186837	31
B2	200 kmph, 12 hrs, Rs.6500	41387654179	30098619501	11289034679	27
B3	300 kmph, 8 hrs, Rs.6500	41387654179	28770497774	12617156405	30
B4	300 kmph, 8 hrs, Rs.8000	41387654179	35411106408	5976547771	14
B5	350 kmph, 6.5 hrs, Rs.6500	41387654179	28438467342	12949186837	31
B6	350 kmph, 6.5 hrs, Rs.8000	41387654179	32754862954	8632791225	21

6 Summary and Conclusions

In this paper, a study was conducted to assess the impact of introducing HSR on CO_2 emissions in India on the proposed HSR corridor of Bengaluru – New Delhi. It was done so by performing a revealed preference and stated preference survey on respondents who travelled to and from New Delhi by air. Six HSR scenarios were proposed with varying speeds, travel time and fares. An analysis was performed on the data collected where the percentage shift of passengers from air to HSR was found, the annual passenger traffic after HSR implementation was calculated, the net change in annual CO_2 emission after HSR implementation and the percentage reduction in CO_2 emission was derived. Using these results, the following conclusions were drawn.

From table 3 it is clear that there is noticeable reduction in CO_2 emission in all of the HSR options from B1 to B6 with the percentage ranging from 14 to 31%. Therefore, the hypothesis that the introduction of HSR in India would lead to a decrease in CO_2 emissions, is accepted. The options B1 and B5 showed the largest reduction in CO_2 emissions at 31% and option B3 was close with 30%. As the options B1 and B5 had the highest reduction in CO_2 emissions, it automatically implies that they had the highest passenger conversion rate as well with 85% each and option B3 also close behind with 83% as shown in figure 3. The result of these calculations also suggests that for long distance journeys with 10 – 12 hours to travel time and for fares moderately charged, many people are willing to use HSR which can contribute substantially in CO_2 emission reduction.

Using these results, a few suggestions were devised in introducing HSR in India to reduce CO_2 emissions. In In the case of Bengaluru –Delhi corridor this can be achieved by running HSR at 200 Km/hr which is possible by upgrading the existing tracks. However, on corridors larger than this, HSR may have to run on higher speeds to achieve overnight journey. From the survey conducted, it is clear that passengers are reluctant to pay fares more than or equivalent to Rajdhani 1st AC fare for travelling by HSR. Any increase in fare above this results in a sharp decrease in passengers and accordingly less CO_2 emission reduction. The statistics obtained from these products may provide a good decision support system to the Govt. of India for setting the speed and fare of HSR such that maximum savings in CO_2 can be achieved.

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