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## ASSESSING THE ENVIRONMENTAL IMPACTS OF HIGH SPEED RAIL FOR POLICY LEVEL DECISIONS IN INDIA

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## ABSTRACT

High-Speed Rail (HSR) can facilitate significant economic, urbanization and environmental impacts, yet its wider impacts are open to debate. In this wake, the prime objective of the research is to study the environmental impacts of High Speed Rail thus creating a tool for supporting policy level decisions. To carry out the research in Indian perspective, case study of Bangalore-Mysore corridor is taken. The study of environmental impacts of the HSR aims to observe the net equivalent $CO_2$ emissions resulting from the new system and the amount of equivalent $CO_2$ emissions saved from passengers switching from other modes to HSR. Revealed and Stated preference survey is conducted for data collection purpose. Discrete Choice Model is developed for calculating the modal shift and market share of each mode. Sensitivity analysis is also conducted using the model to observe the changes in travel behaviour of the passengers with respect to socioeconomic parameters like age, income, gender etc. The outcome of the study indicates that the introduction of new system i.e. HSR, will result in reduction of the greenhouse gas emissions and thus identifies the system as sustainable based on the results. Over all the outcome of the study will be helpful in identifying the best transport system to achieve the 'policy makers' vision towards sustainable development.

*Keywords: High speed Rail, Discrete choice modeling, Carbon Dioxide emissions, India*

## 1. INTRODUCTION

This paper focuses on how the introduction of a High Speed Rail (HSR) system can lead to reduction in amount of equivalent $CO_2$ released in the environment thus emphasizing on its sustainability. According to International union of railways (UIC), a HSR is any passenger train that travel at 250 km/hr or more on a new track or 200 km/hr for an upgraded track.

There is a clear evidence that HSR can create and facilitate significant economic, urbanization and environmental impacts. HSR system can cause redistribution of population from one region to another region, caused by the decreased journey times. Economy of a region can improve significantly by relocation or building of firms and offices in a region due to its improved connectivity with stronger economic regions. HSR is less carbon intensive as compared to other modes of transport and thus HSR has a considerable carbon advantage over car and air travel (ATOC, 2009).

Generally, the main advantages of high-speed rail transit include:

- Stronger engines creating high speed travel;
- Reduction in travel times;
- Reduction in pollution of air, land, water - environmentally-friendly effects;
- Possible reduction in operating costs of traditional transportation modes such as airplanes, autos, buses, and trains;
- Integrating existing transportation modes by linking existing train stations or airports with each other, thus creating a streamlined transportation grid and promoting tourism;
- Enhanced travelling experience with aesthetic qualities of greater comfort, provision of online services, and spacious seating; and
- Promoting economic integration

Policy decisions for HSR projects will be dependent on various factors such as profit making of the organization which requires a high level of demand and also willingness to pay for the new technology, sustainability of the new system etc., thus Indian government is now looking at HSR as a sustainable mode and many feasibility studies have been taken up. Six corridors have been identified for technical and feasibility studies.

For this study Bangalore Mysore corridor is taken as a case study. Bangalore-Mysore is well connected by road and rail network and it takes about 3 hours for one way trip. There is no airline service between the two cities. Thus the target population is passengers travelling between Bangalore to Mysore (in between stations are not considered, since no stoppages have been assumed for HSR route) by three modes i.e. Bus, Train and Private mode. Based on the secondary data analysis, the mode share for Bus, train and private modes is approximately 43.5%, 16.5% and 40% respectively. The analysis is based on discrete choice models using revealed preference and stated preference database. Revealed preference data contain information about the current scenario whereas the stated preference data is based on individuals' stated behaviour in the hypothetical scenarios.

# 2. CURRENT INDIAN RAILWAY SCENARIO AND POLICY ANALYSIS

Indian Railways (IR) is the third largest railway network in the world**.** Today IR operates 19,000 trains each day, comprising 12,000 passenger trains and 7,000 freight trains. It transports 2.65 million tonnes of freight traffic and 23 million passengers every day and 7.2 billion passengers per year. It currently has 1.36 million employees and an annual revenue base of Rs.106,0000 million as projected on March 31, 2012.Currently, Road transport is the most dominant mode of transport. Over 85% of passengers are moved by road in 2004-05 (Planning Commission, 2007). Road dominates short haul journey whereas long haul journey is dominated by rail transport. India does not have any high-speed rail lines capable of supporting speeds of 200 km/h (124 mph) or more, however high-speed corridors have been proposed*.* Six corridors have already been identified for technical studies on setting up of high-speed rail corridors: Delhi-Chandigarh-Amritsar, Pune–Mumbai-Ahmedabad, Hyderabad–Dornakal-Vijayawada-Chennai,Howrah–Haldia,Chennai-Bangalore-Coimbatore-Ernakulam, Delhi-Agra-Lucknow-Allahabad-Patna.

Table 1: Corridors identified for technical studies

| High-Speed Corridor | Route | Stations | Speed (kmph) | Length (km) |
|---|---|---|---|---|
| Howarah- Haldia | Howrah-Haldia | TBD | 250-300 | 135 |
| Delhi - Patna | Delhi-Agra-Kanpur-Lucknow-Varanasi-Patna | TBD | 200 -350 | 991 |
| Delhi - Amritsar | Delhi-Chandigarh-Amritsar | TBD | TBD | 450 |
| Hyderabad - Chennai | Hyderabad-Dornakal-Vijayawada-Chennai | TBD | TBD | 664 |
| Pune - Mumbai - Ahmedabad | Pune-Mumbai-Ahmedabad | 7 | 300-350 | 650 |
| Chennai -Bangalore - Coimbatore-Ernakulam | Chennai-Bangalore-Coimbatore-Ernakulam | TBD | 350 | 649 |

The cost of the high speed line between Ahmedabad & Mumbai is estimated as Rs. 60,000 crores. This cost has also been included under the PPP initiatives. The proposed timeframe is 10 years. Fig1 shows the potential high speed rail lines in India (Indian Railways vision 2020)

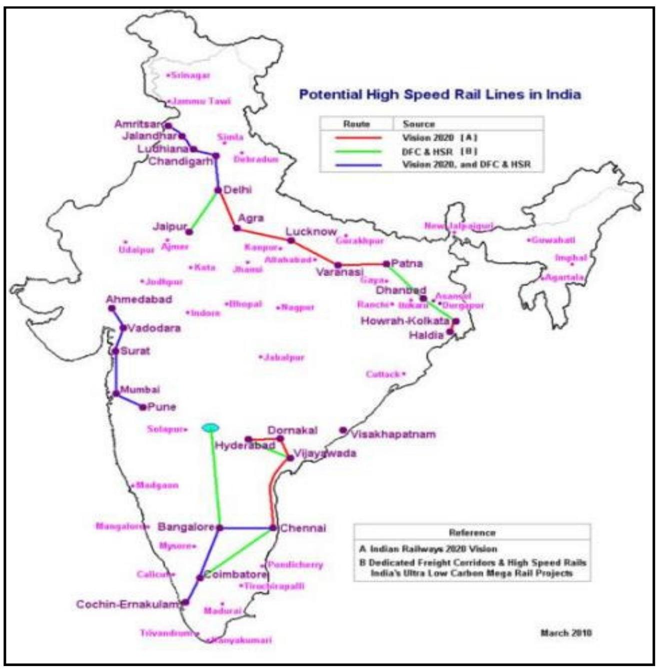


Figure 1: Potential HSR lines in India

A Policy analysis to structure the debate and improve the quality of decision processes on transport infrastructure projects contains several elements such as definition of relevant effects, generation of alternatives, estimation of effects of infrastructure projects and weighing the effects (Rietveld, 1998). Compared to other types of public expenditures, transport infrastructure requires huge planned investments and has a high degree of visibility. Policy makers are usually interested in ex-ante studies which deal with the problem of giving predictions of impacts of projects that have not yet been completed, to discover whether proposed projects can be justified.

Considering Indian scenario with respect to sustainability, policy decision also depends on issues regarding accelerated growth of vehicles which is the main cause in increasing congestion, increase in GHG emissions in major cities in India, increase in fuel price etc.

Singh et al. (2006) indicated the number of vehicles in India is growing at alarming rate thus increasing $CO_2$ emissions. Fig. 2 and Fig. 3 show the number of vehicles in India from 1992 to 2000 and $CO_2$ emissions in India from 1992 to 2000.

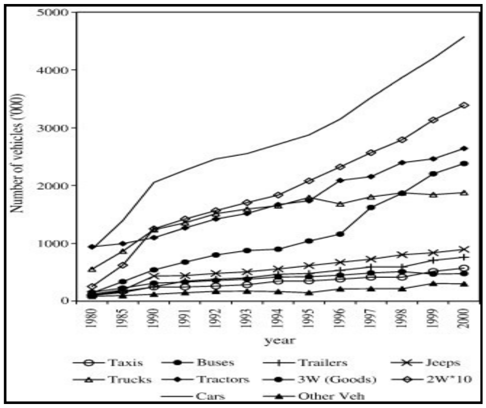


Figure 2 Number of vehicles from 1990 to 2000, Singh et al. (2006)

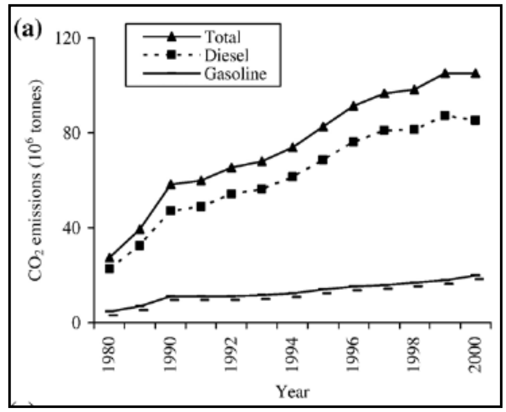


Figure 3: $CO_2$ emissions from 1990 to 2000, Singh et al. (2006)

Ramachandra et al. (2008) asserted on the fact that main contributors in India transport is from the road sector and encouraging the use of public transport in place of private transport and various urban policies such as metro railway, transport management etc will curtail transport emissions especially in major cities in India. Fig. 4 shows the vehicular emissions in major cities in India.

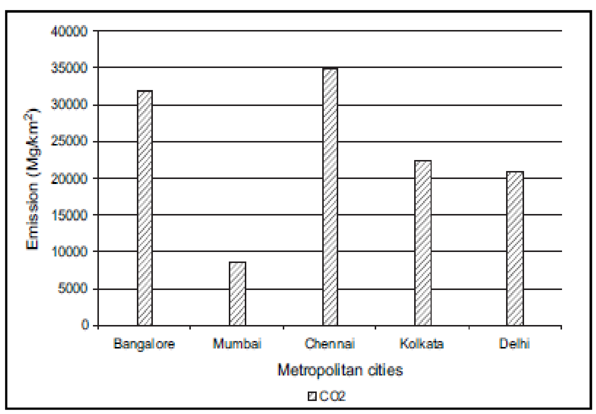


Figure 4: $CO_2$ emissions for major cities in India, Ramachandra et al. (2008)

Indian planning commission (2007) predicts the change in the modal share and indicates that there will be a substantial shift from rail to road given the current scenario remains the same and thereby suggesting that proper planning has to be done to reduce the mode share gap. Fig. 5 shows the Inter modal share.

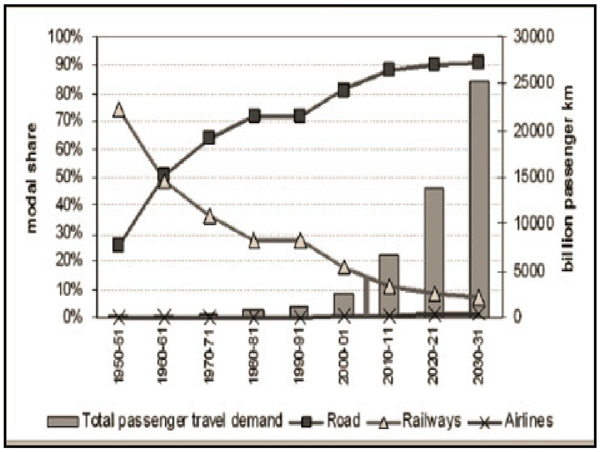


Figure 5: Inter-modal share in India, Planning commission (2007)

Thus policy makers seek solutions which can assist in tackling these problems for which these impact studies are used to evaluate the projects and throw light on issues like achieving sustainability, preferable sector to be given thrust etc. Hence there is a need for scientific decision support for policy level decisions.

# 3. LITERATURE REVIEW

There is a continuous debate on the effects of HSR on the environment. Many researchers has developed approaches to estimate demand and thus the modal shift and then comparing the environmental impacts of the HSR.

Åkerman (2010) used a life cycle perspective to analyze Europabanan,a proposed high-speed rail track in Sweden. He used life cycle assessment and scenarios including future developments regarding vehicle technology, bio-fuels, mix of electricity supply and transport volumes. Greenhouse gas emissions are the main impact category considered, but energy use was also examined. He used the rail travel time which is generally the most important driver of the rail/air market share. Here he assumed the market shares using travel time which were consistent with Gleave (2006), López-Pita and Robusté (2005) and Givoni (2006).He also assumed the shift from car to rail which is consistent with Inglada (1996) and González-Savignat (2004). He suggested that widening in one transport sector reveals a reduced need for e.g. cars, roads and airports, which in turn means the emissions from expansion of other sectors are avoided. These system effects are seldom considered in studies of new railways. The HSR and Freight measures scenario 2025/2030 also gives significant reductions in oil use, which in the base case amount to 2.5 TWh annually.

Most of the studies showed that HSR is more environmental friendly when compared to other transport systems. Verma et al.(2010) described HSR as a sustainable mode while comparing it with the current mode scenario in Indian context. They compared HSR and conventional rail using parameters like per-passenger km, occupancy levels and electricity decarbonization. They concluded that HSR is anticipated to produce lower GHG emissions than Conventional Rails. On average, HSR (at 30.3g $CO_2$ eq/p-km) is expected to result in around 15% less GHG emission than conventional rail (at 35.7g $CO_2$eq/p-km) in 2025.

Association of Train Operating Companies analysis for Greengauge (ATOC, 2009) indicated that, at any given load factor, high speed rail already outperforms both car and short haul jet aviation even without electricity being decarbonised. They stated that comparing the carbon performance of high speed rail with competing modes is problematic, in large part because load factors vary widely.

The Center for Clean Air Policy (CCAP, 2005) used passenger projections and diversion rates to calculate the carbon dioxide ($CO_2$) emissions saved from passengers switching to high speed rail from other modes—air, conventional rail, automobile and bus and subtracted the estimated emissions generated by high speed rail to estimate high speed rail's net emissions impact. They concluded that HSR will result in reduction in $CO_2$ emissions.

Kato and Shibahara used a life cycle assessment method for evaluating environmental impacts of inter-regional high speed mass transit projects. They proposed an LCA method in the planning phase for evaluating life cycle carbon dioxide emissions. They compared the carbon emissions between the Shinkansen, MAGLEV system and airplane modes. They concluded that even by taking difference in the passenger carrying capacity, MAGLEV carbon emissions over its life cycle will be twice as that of the Shinkansen. They observed that approximately 90% of the emissions are during the running stage thus making low electricity consuming train desirable. When compared to airplane mode Shinkansen carbon emissions over its life period was lesser.

Kosinski et al. (2010) analyzed High-Speed Rail‘s potential to reduce $CO_2$ emissions from transportation in the United States. By comparing utilities, a probability of taking HSR was therefore gained and used as the mode shift. They analyzed eight different regional networks, with the predicted shifts from air to HSR ranging from 20.8% to 45.7% and the predicted shifts from auto to HSR ranging from 0.7% to 6.3%. They emphasized that to enable $CO_2$ reductions requires proper planning for HSR lines to continue at brisk pace and construction to begin in near future.

# 4. PROPOSED METHODOLOGY

The framework is designed to be carried out in three phases, starting from the data collection phase which includes problem identification and collection of required data. The second phase deals with discrete choice modeling to obtain HSR mode share and diversion from other modes and the last phase is the analysis phase in which net $CO_2$ emissions from each mode are determined and sensitivity analysis was conducted using the models. Figure 6 shows the flowchart of the proposed methodology.

**PROPOSED METHODOLOGY**

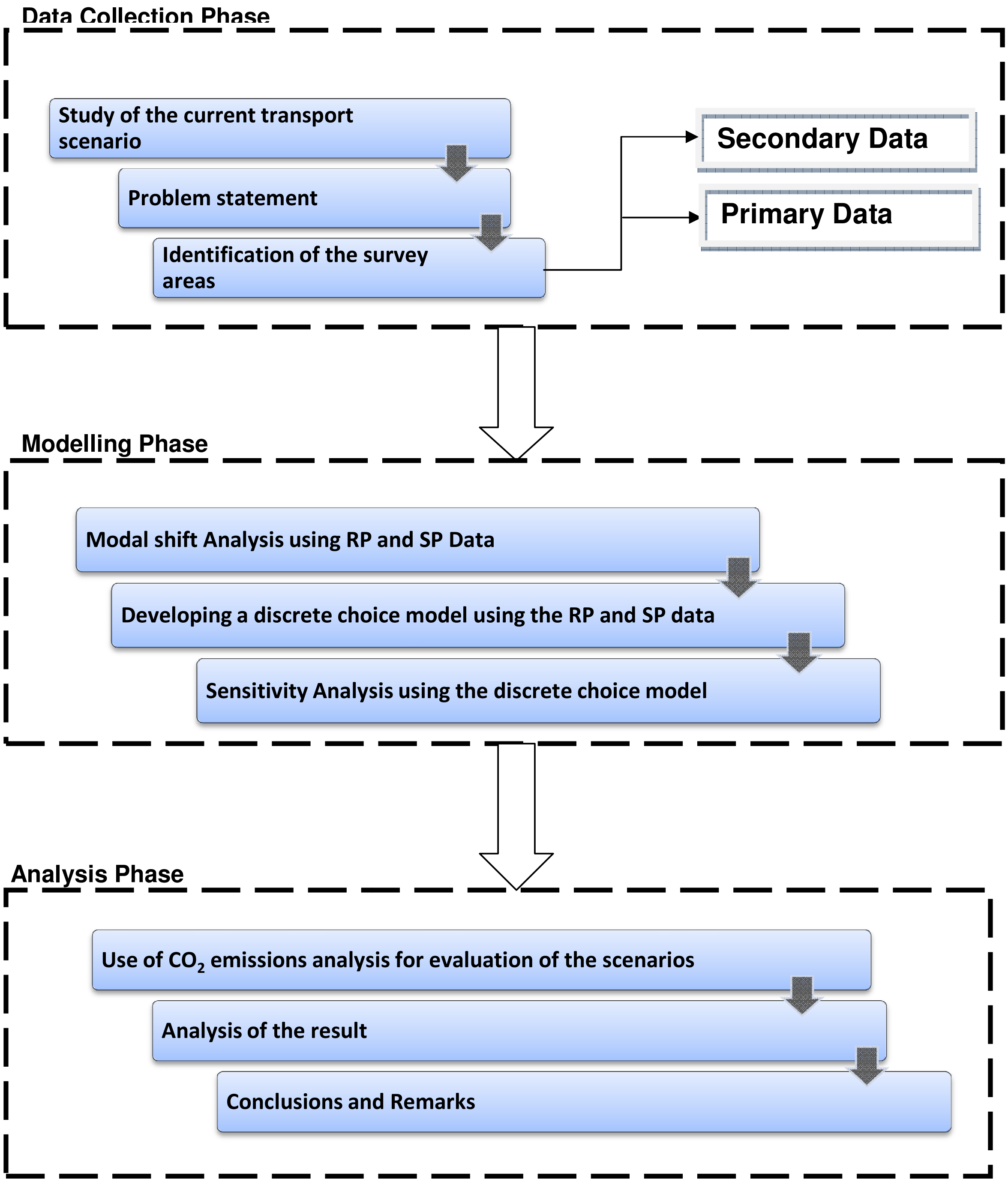


Figure 6: Flow chart of the Methodology

## 4.1 The Data Collection Phase

This phase includes the data collection to be used in the technical phases and evaluation. Analysis of passenger's perception is carried out by discrete choice analysis based on RP (Revealed Preference) and SP (Stated Preference) data. González-Savignat (2004) used SP techniques to evaluate the potential of high speed rail to compete with air market. He proposed HST as a hypothetical situation and analyzed passenger's preference over air market. RP data contains information about the current market situation whereas SP data contains information about passenger's preference in a hypothetical situation. Various researchers have provided suggestions on different aspects related to SP designs. Regarding data collection use of face-to- face personal interview technique is emphasized by Hensher et al. (1992). Use of preference surveys to estimate behavior changes assume that people are able to accurately predict their response to a facility improvement or policy change. Frequently, when people are asked if they will change their behavior in the future, the responses significantly over predict the number of people who actually change their behavior.

## 4.2 The Modelling Phase

A Discrete Choice model is developed to study the mode choice behaviour of the passengers with respect to the change in the mode variables. The data collected is used to estimate the mode choice parameters.

### *4.2.1 Model Structure overview*

Discrete choice model postulates that the probability of individual choosing given option is a function of their socioeconomic characteristics and the relative attractiveness of the option. Discrete choice models assume utility-maximizing behaviour by the decision maker ( McFadden, 1974 ). It states that the utility of alternative j for individual q has the expression

$$Uiq = Viq + \varepsilon iq \qquad (1)$$

Viq is the systematic or representative utility and $\varepsilon_{iq}$ is reflecting unobserved individual idiosyncrasies of taste. The later part is also termed as ASC (Alternative specific constant). The dependent variable represents individual's choices. Estimation provides the probability distribution of the dependent variable for every individual observation. Hence, the probability that individual q chooses alternative j is given by

$$P_{jq}= P( V_{jq}+\varepsilon_{jq} > V_{iq}+\varepsilon i_{q}) \qquad (2)$$

This probability will depend on the hypotheses formulated about the distribution of the vector of random terms $\varepsilon_{jq}$.

## 4.3 The Analysis Phase

The next phase, following the modelling, is the evaluation of the scenarios, by analyzing the net savings in the annual emissions of $CO_2$. Here equivalent $CO_2$ emissions are estimated for two scenarios: Base scenario and HSR scenario. In the base scenario equivalent $CO_2$ emissions are calculated for the present or the current scenario and in the HSR scenario emissions are calculated for the hypothetical situation i.e. in the presence of the new system. Daily passenger-km is derived by multiplying the daily number of passengers with the distance of the trip.[1] These daily passengers-km are converted into annual passenger-km and then emissions are determined by using the standard emissions value for different modes. Table 4 shows the rate of equivalent $CO_2$ emissions per passenger-km for different modes.

Table 2: Rate of emissions for different mode

| Vehicle Type | $CO_2$ equivalent grams / passenger-km |
|---|---|
| Bus | 75 |
| Train- Diesel | 74 |
| Train- electric | 54 |
| Train- overall | 61 |
| Two Wheeler | 79.6 |
| Car | 105.3 |
| HSR | 29.5 |

(Source: ATOC 2009, Bajracharya 2008)

# 5. CASE STUDY: BANGALORE-MYSORE CORRIDOR

A Pilot Survey was conducted with an objective to understand the current travel behavior of the passengers and also to fine tune the questionnaire design. Revealed preference survey was conducted with an objective to study the socio economic charecterstics and travel behaviour of the passengers traveling between Bangalore and Mysore. Stated prefernce survey was aimed to analyse the preference of the passengers and their willingness to shift to HSR, from their current mode for the same trip, when provided with different choice situations.[2] The questionnaire was divided into two categories : household or personal information and trip information. Travel time was divided into two categories: In-vehicle travel time and Out-vehicle travel time. For SP survey, variables can have two to three levels depending on the requirement. Here two levels of the travel time by HSR has been taken i.e. 30 minutes and 45 minutes (Based on the definition of a high speed rail and its minimum speed requirement- first level speed assumed was 300 km/hr and second level speed assumed was 200 km/hr). Three levels of fare structure were taken i.e. low fare, high fare and a monthly pass scheme. The cost of low fare was Rs. 450, for high fare cost was Rs. 600 and the monthly pass cost was Rs. 10,000.[3] Thus combining two levels of time and three levels of fare, total choice situations per respondent were six.

Considering all modes a total of 290 interviews were completed. Each individual was given 6 choice situations, thus making a total of 1740 observations. Considering each mode, for bus mode, 103 interviews were completed thus making 618 observations. For train mode, 95 interviews were completed thus making 570 observations. For Car and two wheeler mode, 92 interviews were completed thus making 552 observations. Out of these observations, 120 observations were kept for the validation of the bus model, 90 observations for private mode model and 96 observations for train model.

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[1] The distance between Bangalore to Mysore is approximately equal to 144 km for both highway and rail network.

[2] Survey was carried out for 4 weeks, starting from $10^{th}$ April 2012. Bus users were interviewed at the KSRTC satellite bus stand while train users were interviewed by boarding the trains and private mode users were interviewed at restaurants located at the state highway 17.

[3] The cost levels were decided based on the minimum charge per km for a HSR system. The monthly pass cost was decided on the method used by other public transport authorities i.e. to charge passenger less than half of the trips made.

The study is further analyzed at different aggregation levels, as per the household income, different fare levels and the current mode. This helps to understand the shift as per the respective category.

## 5.1 Descriptive Analysis of the Sample

Table 3 shows descriptive analysis of the sample with respect to Socioeconomic Characteristics i.e. trip purpose, Gender, Age and Annual Household Income. Here we observe that majority passengers travelling are Male (81%). 69% of the passengers travelling are aged between 20-50 years indicating trip purpose to be mainly work. Passengers aged >50 prefer train over other modes indicating the comfort factor is important for older age group passengers. Low income group passengers prefer train because of its low fare.

Table 3 shows percent of cases willing to shift to HSR for different mode at different Fare level.

| | Mode | Bus | Train | Private | Total |
|---|---|---|---|---|---|
| **Trip Purpose** | Work or Education | 312 (63%) | 192 (41%) | 234 (51%) | 738 (51%) |
| | Recreational | 186 (37%) | 282 (59%) | 228 (49%) | 696 (49%) |
| **Gender** | Male | 396 (80%) | 390 (82%) | 372 (81%) | 1158 (81%) |
| | Female | 102 (20%) | 84 (18%) | 90 (19%) | 276 (19%) |
| **Age** | <20 | 126 (25%) | 66 (14%) | 54 (12%) | 246 (17%) |
| | 20-50 | 348 (70%) | 282 (59%) | 360 (78%) | 990 (69%) |
| | >50 | 24 (5%) | 126 (27%) | 48 (10%) | 198 (14%) |
| **Income** | < 2 Lakhs | 42 (8%) | 96 (20%) | 36 (8%) | 174 (12%) |
| | 2-5 Lakhs | 228 (46%) | 216 (46%) | 186 (40%) | 630 (44%) |
| | 5-8 Lakhs | 132 (27%) | 78 (16%) | 156 (34%) | 366 (26%) |
| | > 8 Lakhs | 96 (19%) | 84 (18%) | 84 (18%) | 264 (18%) |

Table 4 shows percent of cases willing to shift to HSR for different mode at different Fare level.

Table 4 Percent of cases willing to shift to HSR for different mode at different Fare level

| Current Mode | Fare level | No. of passengers Shifting to HSR | % Shift | Total % Shift from each mode |
|---|---|---|---|---|
| **Bus** | 450 | 112 | 67.47 | **34.53** |
| | 600 | 52 | 31.32 | |
| | Monthly Pass | 8 | 4.82 | |
| **Train** | 450 | 96 | 60.75 | **32.27** |
| | 600 | 56 | 35.44 | |
| | Monthly Pass | 1 | 0.632 | |
| **Private mode** | 450 | 95 | 61.68 | **33.76** |
| | 600 | 57 | 37.01 | |
| | Monthly Pass | 4 | 2.59 | |

## 5.2 Effect of Socio Economic Parameters on % shift to HSR

Here the % shift is determined from the sample data with respect to different socio economic parameters of the passengers.

### *5.2.1 Income*

Table 5 shows the % shift to HSR from different modes with respect to the income levels of the passengers. The data suggests that passengers belonging to higher income group are more likely to shift to the new hypothetical system. Policy makers should focus on implementing a safe, comfortable and efficient new transport system to get the desired mode share which in turn will reduce the number of vehicles plying on roads as higher income group have a higher tendency to use the private modes.

Table 5: Percent of cases willing to shift to HSR from different modes for different income class.

| **Mode** | **Income (in lakhs)** | **No. of passengers** | **No. of passengers shifting to HSR** | **% Shift** |
|---|---|---|---|---|
| **BUS** | < 2 | 42 | 7 | **16.66** |
| | 2 - 5 | 196 | 64 | **32.65** |
| | 5-8 | 132 | 59 | **44.69** |
| | > 8 | 78 | 40 | **51.28** |
| **TRAIN** | < 2 | 96 | 0 | **0** |
| | 2 - 5 | 216 | 71 | **32.87** |
| | 5-8 | 78 | 28 | **35.89** |
| | > 8 | 84 | 54 | **64.28** |
| **PRIVATE** | < 2 | 36 | 3 | **8.33** |
| | 2 - 5 | 186 | 53 | **28.49** |
| | 5-8 | 156 | 54 | **34.61** |
| | > 8 | 84 | 46 | **54.76** |

### *5.2.2 Age*

Table 6 shows the % shift to HSR from different modes with respect to passenger's age. There is a considerable shift for the age group >50, the reason behind was the comfort factor related to rail transport. Majority shift was from the age group 20-50 due to the fact that reduction in travel time is crucial for work trips especially business trips.

Table 6: Percent of cases willing to shift to HSR from different modes for different age group.

| **Mode** | **Age** | **No. of passengers** | **No. of passengers shifting to HSR** | **% Shift** |
|---|---|---|---|---|
| **BUS** | < 20 | 126 | 31 | **24.60** |
| | 20 – 50 | 348 | 136 | **39.08** |
| | > 50 | 24 | 5 | **20.83** |
| **TRAIN** | < 20 | 66 | 16 | **24.24** |
| | 20 – 50 | 282 | 95 | **33.68** |
| | > 50 | 126 | 42 | **33.33** |
| **PRIVATE** | < 20 | 54 | 5 | **9.25** |
| | 20 – 50 | 360 | 136 | **37.77** |
| | > 50 | 48 | 15 | **31.25** |

*5.2.3 Gender*

Table 7 shows the % shift to HSR from the different modes with respect to the gender of the passengers. The data indicates that % of male shifting to HSR is approximately for all the modes.

Table 7: Percent of cases willing to shift to HSR from different modes for different gender.

| Mode | Gender | No. of passengers | No. of passengers shifting to HSR | % Shift |
|---|---|---|---|---|
| **BUS** | Male | 396 (80%) | 142 | **35.85** |
| | Female | 102 (20%) | 30 | **29.41** |
| **TRAIN** | Male | 390 (82%) | 137 | **35.12** |
| | Female | 84 (18%) | 16 | **19.04** |
| **PRIVATE** | Male | 372 (81%) | 133 | **35.75** |
| | Female | 90 (19%) | 23 | **25.55** |

## 5.3 The Model

The utility function associated to a alternative (mode) i, is given by the following equation,

$$U = \beta_{0i} + \beta_{1i}(X_{1i}) + \beta(X_{2i}) + \text{......................................} B(X_{ki}) \qquad (3)$$

where $X_1$ .... $X_{ki}$ is the attributes for mode i and $\beta_{1i}$…$\beta_{ki}$ is the weight (or parameter) associated with attribute $X_1$ …$X_k$ of alternative $(\text{mode})_i$. The main variables, used for random utility models are the income, in vehicle travel time, out vehicle travel time and travel cost. The variables such as income representing individual attribute, which will have same values for both options, will be put into only one of the utility equation. The variables dependent on the alternative mode, such as travel time, travel cost will appear in both equations. (Ben-Akiva, M. and Lerman, S.R, 1985). Here shift from each mode is determined by comparing each mode utility with the HSR utility equation then a binary logit model is used to determine the mode share.

$$U_{BUS} = ASC_1 + \beta_1 * BUS\_ITT + \beta_2 * BUS\_OTT + \beta_3 * BUS\_CO + \beta_4 * INCOME \qquad (4)$$

$$U_{HSR} = ASC_2 + \beta_1 * HSR\_ITT + \beta_2 * HSR\_OTT + \beta_3 * HSR\_CO \qquad (5)$$

Similarly other mode's utility was also compared with the HSR mode.

*5.3.1 Estimation*

Estimation results are shown in Table 8. All parameters have the expected sign and are significant at the 95% confidence level. The alternative specific constants, taking HSR as a reference were positive indicating that other modes are preferred if the effect of the other attributes were zero. Income parameter was negative for all modes indicating higher income groups have greater tendency to shift to HSR.

Table 8: Estimation Results

| Parameter | Value | Standard error | t-test |
|---|---|---|---|
| **BUS MODE** | | | |
| ASC1 | 5.66 | 1.40 | 4.04 |
| ASC2 | 0.00 | fixed | |
| Beta1 | -7.68 | 1.10 | -6.99 |
| Beta2 | -2.92 | 0.813 | -3.60 |
| Beta3 | -1.75 | 0.224 | -7.81 |
| Beta4 | -0.0107 | 0.00460 | -2.33 |
| **TRAIN MODE** | | | |
| ASC1 | 1.18 | 1.86 | 0.64 |
| ASC2 | 0.00 | fixed | |
| Beta1 | -2.43 | 1.18 | -2.05 |
| Beta2[4] | - | - | - |
| Beta3 | -1.20 | 0.148 | -8.11 |
| Beta4 | -0.0337 | 0.00577 | -5.84 |
| **PRIVATE MODE** | | | |
| ASC1 | 2.18 | 0.987 | 2.21 |
| ASC2 | 0.00 | fixed | |
| Beta1 | -2.45 | 0.649 | -3.77 |
| Beta2 | -5.41 | 0.979 | -5.52 |
| Beta3 | -0.657 | 0.0755 | -8.71 |
| Beta4 | -0.0234 | 0.00532 | -4.40 |

### *5.3.2 Evaluation of Scenarios and sensitivity analysis for Income parameter*

The equivalent $CO_2$ emissions for the two scenarios are calculated and net % savings in the HSR scenario is determined with respect to the base scenario.

*Base Scenario:*

Here net emissions are calculated without the presence of the new system i.e. the HSR or net emissions in the current scenario. Table 9 shows the total emissions in the base scenario.

Table 9: Equivalent $CO_2$ emissions in Base scenario

| Mode | Annual $CO_2$ Emissions (Tons) |
|---|---|
| **Bus** | 112090.77 |
| **Train** | 34305.912 |
| **Private** | 129335.075 |
| **Total** | **275731.757** |

[4] The Station for the Hypothetical HSR system was assumed to be the same as the current railway station, thus the out vehicle time parameter becomes redundant and hence it is not included in the model.

*HSR Scenario:*

Here net emissions are calculated in the presence of the new system i.e. HSR or net emissions in the hypothetical scenario. Table 10 shows net emissions for different fare levels.

Table 10: Net emissions of different Fare level

| Choice | Emissions from Train | Emissions from Bus | Emissions from T W | Emissions from Car | Emissions from HSR | Total Emissions | % Savings |
|---|---|---|---|---|---|---|---|
| **30 min, Rs. 450** | 26573.77 | 53927.32 | 36744.60 | 26651.74 | 45457.61 | 189355.05 | **31.33** |
| **30 min, Rs. 600** | 32024.48 | 103068.05 | 39180.23 | 47406.45 | 16775.18 | 238454.41 | **13.52** |
| **45 min, Rs. 450** | 28191.89 | 82516.430 | 37899.80 | 33930.06 | 30962.65 | 213500.84 | **22.57** |
| **45 min, Rs. 600** | 32558.82 | 109008.35 | 39661.97 | 55304.58 | 11788.81 | 248322.55 | **9.941** |

The discrete choice model is used to study the change in the travel behaviour of the passengers with respect to the change in the values of the different variables. This sensitivity analysis will help in the policy level decision making by allowing them to consider various situations and thus choose the best possible scenario. Here keeping other parameters same the income parameter is varied to see the effect of this parameter on % emissions saved. Table 11 shows the change in % savings in net $CO_2$ emissions as income parameter increases for the passenger population. This shows that % savings increases as income of the passenger increases which shows that higher income group are more likely to shift to new system.

Table 11: Emissions from different modes for different income.

| Income | Emissions from Train | Emissions from Bus | Emissions from T W | Emissions from Car | Emissions from HSR | Total Emissions | % Savings |
|---|---|---|---|---|---|---|---|
| **30 min, Rs. 450** | | | | | | | |
| **2 lakhs** | 12007.07 | 12153.186 | 36607.37 | 28190.196 | 68553.131 | 157510.95 | **42.87** |
| **3.5 lakhs** | 8409.75 | 10521.198 | 35937.98 | 16602 | 74429.6 | 145900.52 | **47.09** |
| **6.5 lakhs** | 3626.16 | 7832.754 | 19349.61 | 15528.404 | 88410.64 | 134747.56 | **51.13** |
| **9 lakhs** | 1663.99 | 6094.332 | 14521.62 | 7061.384 | 90043.34 | 119384.66 | **56.70** |
| **30 min, Rs. 600** | | | | | | | |
| **2 lakhs** | 26248.83 | 70246.44 | 39180.35 | 56042.818 | 30058.36 | 221776.79 | **19.56** |
| **3.5 lakhs** | 22734.88 | 65961.48 | 37506.87 | 48262.014 | 36243.39 | 210708.63 | **23.58** |
| **6.5 lakhs** | 14302.67 | 57068.334 | 36607.37 | 25793.974 | 50447.7 | 184220.05 | **33.19** |
| **9 lakhs** | 8076.31 | 49602.186 | 32260.51 | 11068 | 62132.43 | 163139.43 | **40.83** |

Table 11 shows the decrease in the % savings of $CO_2$ emissions as fare level increases for all the modes. Low % savings from the shifting of the train mode users indicate that very less % of shift of the train users to HSR will be observed even for the lowest fare level. % savings from the shifting of private mode users are high compared to shifting of bus users to HSR system.

# 6. CONCLUSIONS

This paper analysed the environmental impacts of HSR for policy level decisions in India. Analyzing the choice set data, the overall figure showed an indication of about 33.5 % of the respondents willing to shift towards the HSR. Analyzing each mode 34.53 % of bus, 32.37% of train and 33.76% of private mode passengers said that they are willing to shift to HSR. Analyzing from income level point of view, higher income class showed greater tendency to shift to HSR than the lower and middle income class. Analyzing with respect to age group, older group are more likely to use train system and majority shift to HSR system was observed from age group 20-50 years. Male are more likely to shift to the new system.

## 6.1 Conclusions for policy level decisions

- As per fare level is concerned the maximum mode share and thus the maximum % savings in emissions is achieved when the fare is lowest. But looking into other aspects such as profit making for the organization, the fare level selection is a complex situation. It depends on the good judgment of the policy decision makers. If best scenario is to be achieved, then going for subsidy or fund generating from outside the fare box can be looked upon.
- From the analysis it is clear that a major share of savings in Carbon emissions are coming from the private mode users as the emission rate of the private mode is high. Thus the policy decision makers should look in all possible ways to make rail based mode more attractive. Instead of investing in the highway section, improvement can be done in the railways section and the movement within the city can be looked upon.
- Higher income group people show more tendency to shift towards the HSR system. Thus policy maker can see it as a viable solution to curtail the number of growing vehicles in the city given that the new system is safe, comfortable and efficient.
- The Older age group people are more likely to shift towards the HSR system thus comfortable criteria for the new transport system should not be underestimated and should be designed for proper load factor.
- Keeping gender as a factor male population is more likely to shift towards the new system. Response during SP survey revealed that for the female category safety becomes an important criterion and thus there stated response also depends on operational timings of the new system.

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