ABSTRACT

Indian Railway provides an important mode of public transport in India. This is the most commonly used and cost effective long-distance transport system of the country. Indian Railways has played an immense role in assimilating various disjoint sectors and thereby acting as a catalyst in stimulating the Indian economy. It is also the link between various industrial, agricultural production centres with their corresponding markets. It links places, enabling large-scale, rapid and low-cost movement of people from different backgrounds across the length and breadth of the country. In India the cultural diversity, inequitable job distribution, economic disparity leads to a demand for an affordable and reliable mode of transportation to fulfil the need for travel across the country. High-speed rail (HSR) is argued to be an efficient transportation mode that can fulfil this demand gap of faster intercity movement of passenger traffic. As Indian government plans to invest in this new technology, strategic decisions pertaining to type of corridor, speed of HSR, HSR technology, given the competition scenario on that corridor becomes vital. While there is a considerable amount of studies on HSR in developed nations especially the European countries, very little is available for the developing nation's scenario. Does the region where the study is done, matters? Passenger's travel and mode choice behaviour lies at the roots of the competition setup between the modes and this passenger's behaviour vary from corridor to corridor making study area a vital component in the competition scenario. Furthermore, corridors length might play a significant role in the strategic decision over the speed of the HSR services thereby underlining the implications of the region of study in the competition setting.

Moreover, the vast majority of the literature till date analyses airline competition and relatively little has been published on the rail sector and there is no significant work on studying the impacts of HSR in Indian context. Therefore, present study tries to model these competition scenarios from Indian perspective giving insights in the strategic interactions of mode operators using a game theoretic framework. As mode choice behaviour drives the competition game between the modes, this study develops various models like oligopoly models, discrete choice modelling and value of time models to determine the modal share in the new scenario.

Firstly, a duopoly model is developed to analyse the impact of inter-modal competition between airlines and high-speed rail (HSR) services, where airlines are assumed to maximize profit and HSR maximizes a weighted sum of profit and social welfare. A basic competition model and two extended models were developed by relaxing assumptions on homogeneous passengers and uniform pricing in the respective models. Further incorporating frequency in the first extended model presented analogous results when compared to the basic model. In the final extension under price discrimination for different classes of travel - Business and Leisure - simulation provided interesting insights. It was found that treating different classes as separate choices for heterogeneous passengers results in different relationships with various decision variables as compared to the basic model, hence justifying the importance of the relaxation of homogeneous passengers under uniform pricing assumption. The analysis showcase possible scenarios under which HSR competes with airlines on different corridors with different transit and passenger characteristics. This study used price and travel time as the most important

quality differentiator between the modes thereby implying the centrality of value of time of passengers in mode choice behaviour and hence developing a value of time method to determine modal share is the extension of this work thereby providing the platform for the following study.

Next, a value of time (VOT) model under a game theoretic framework is formulated which is applied in order to evaluate the competition scenario between High Speed Rail (HSR) and conventional transport modes in Indian scenario. In this study, two corridors; Bangalore-Delhi (long corridor) and Bangalore-Mysore (short corridor) is taken as case studies to model HSR-Airlines and HSR-Bus competition respectively. The competition scenario between the operators are modelled considering the competition over fare and frequency to maximize their profit. Speed of HSR is taken as a strategic variable in the game with three levels of high speed, *{Low-H, Medium-H, High-H}* in the longer corridor and with two levels of high speed in the shorter corridor, *{Low-H, High-H}.* A three-stage game is formulated with the entrant playing its speed strategy in the first stage followed by optimal fare and frequency selection by both the modes. Passengers are considered to be heterogeneous in nature by assuming a continuous distribution of Value of Time (VOT). Revealed and stated preference survey data is used to determine the VOT of passengers on these corridors and a lognormal curve is fitted to determine the parameters of the distribution. Sub-game perfect Nash equilibrium is computed for various game scenarios characterized by sunk and variable costs given a profile of demand and the corridor VOT parameters. A Cooperative scenario is also developed where the players maximize a combined profit function. For Bangalore-Delhi corridor, for the given VOT distribution of the passengers, medium level of high speed is the equilibrium strategy for low variable costs whereas for high variable costs under low sunk cost, high speed is the equilibrium strategy. For Bangalore-Mysore corridor having low demand, the market equilibrium is blockaded entry i.e. HSR will stay out of the market except the first game scenario. For high demand, playing high level of high speed is the equilibrium strategy and bus will accommodate the entry. Cooperative scenario results in increase in optimal fares and reduction in optimal frequencies depicting the monopolistic behaviour of the market. Value of time models do not incorporate individual specific variables and therefore discrete choice models can be used as an alternative for determining the modal share.

Further, this study investigates the same competition using discrete choice modelling approach under the same game theoretic settings. Discrete choice models were estimated using revealed and stated preference data of the corridor. These models were used to determine the modal share in the new hypothetical scenario which were in turn used in defining objective functions such as profits and social welfare. Changing the objective function to social welfare maximization results in different equilibrium solution for Bangalore-Delhi corridor. Thus, impact of different combinations of demand, cost structures and objective functions are explored on the market equilibrium thereby providing interesting insights in this area. These models do not account for passenger's heterogeneity and integrating a mixed logit model with game theoretic framework will relax this assumption.

Subsequently, this study estimated a mixed logit model under a game theoretic framework to incorporate passenger's heterogeneity in the mode choice model. The estimation results of mixed logit model indicate that passengers are heterogeneous in nature in perceiving travel

time and cost and incorporating this heterogeneity in the competition model will provide more realistic results as it relaxes all the assumptions in the Multinomial Logit model. Results demonstrates variation in Nash equilibrium for high demand under these different choice model formulations. Thus, effect of mode choice formulations is explored on the market equilibrium thereby providing interesting insights in this area.

One of the major contribution of this research is the incorporation of speed as a strategic variable and this study highlights this in the competition study by analysing the variation in the Nash equilibrium of the game thereby assisting in the subsequent decision of choosing the service speed. Another contribution of this study is the formulation of the analytical model segregating leisure and business class and its impact on the equilibrium of the game. The prominence of VOT parameters on the Nash equilibrium was also demonstrated hence policy decision will be different for different corridors as passenger's characteristics varies with region of study. Discrete choice models also captured these different equilibriums under different objective functions formulations like social welfare which might be the objective function for a fully public railway sector in India. This study also contributes by integrating mixed logit model in a game theoretic framework consequently capturing passenger's heterogeneity impact on the market dynamics. Hence, understanding these changes in dynamics of the market after the introduction of the new mode provide a scientific tool to enable the policy makers to make better judgement in taking these policy level decisions.