VOLUME 38 • FEBRUARY 2013 ISSN: 0739-8859

RESEARCH IN
TRANSPORTATION ECONOMICS

Economics of Sustainable Transport in India

Ashish Verma
Guest Editor

Research in Transportation Economics 38 (2013) 67–77

Contents lists available at SciVerse ScienceDirect

Research in Transportation Economics

journal homepage: www.elsevier.com/locate/retrec

Sustainable urbanization using high speed rail (HSR) in Karnataka, India

Ashish Verma [a,b,*], H.S. Sudhira [c,d], Sujaya Rathi [e,1], Robin King [e,2], Nibedita Dash [a]

[a] Department of Civil Engineering, Indian Institute of Science (IISc), Bangalore-560012, Karnataka, India
[b] Centre for infrastructure, Sustainable Transportation, and Urban Planning (CiSTUP), Indian Institute of Science (IISc), Bangalore-560012, Karnataka, India
[c] Gubbi Labs, Karnataka, India
[d] Indian Institute for Human Settlements, Bangalore, Karnataka, India
[e] Center for Study of Science, Technology & Policy, Old CAIR Building, Raj Bhavan Circle, Bangalore-560 001, India

ARTICLE INFO

Article history:
Available online 6 July 2012

Keywords:
High speed rail
HSR
Urbanization
Karnataka
India

ABSTRACT

Considering the present trends of urbanization and motorization in India, there is an urgent need for integration, revitalization and renewal of the smaller towns and cities to make urban areas in India more sustainable. Unless our regional space is reorganized to upgrade development of towns and cities and integrate them with each other and the larger cities, the urbanization process in India will become unsustainable. It is argued that High Speed Rail (HSR) can play a role in achieving this more balanced and sustainable development of towns and cities, opening up opportunities for growth across a wider, interconnected, region, with the benefit of taking the pressure of the larger cities to absorb additional burgeoning populations. This paper will make the case that in the current Indian context, current patterns of mega-city growth are unsustainable, and that HSR can play an important role in providing opportunities for medium and smaller size cities through their interconnections. It begins by highlighting the role that railways have played in India and other countries, noting that merely economic analysis of their costs and benefits generally underestimated their contributions to development. It then provides an introduction to HSR and its potential impact in general, before applying this to the example of the State of Karnataka in South India.

1. Introduction

Considering the present trends of urbanization and motorization in India, there is an urgent need for integration, revitalization and renewal of the smaller towns and cities to make urban areas in India more sustainable.

Urbanization in India has seen booming megacities. According to the 2001 Census of India, nearly 63 per cent of the Class I city population (about 108 million) lived in the 35 million-plus cities (about 39 per cent of total urban population). Three cities have a population of more than 10 million. Four others cities had crossed the four million mark. Amongst the mega-cities, the top three – Mumbai, Kolkata and Delhi accommodated over 65 per cent (about 42 million) of the mega-city population (about 15 per cent of the total urban population).

According to McKinsey Global Institute (2010) estimates, the population of urban India is likely to increase from 340 million (30 per cent) in 2008 to 590 million (40 per cent) in 2030. It also projects that the States of Punjab, Gujarat, Tamil Nadu, Karnataka and Maharashtra will be more than fifty-per cent urbanized, which means growth occurring in cities of all sizes. Unless our regional space is reorganized to upgrade development of towns and cities and integrate them with each other and the larger cities, the urbanization process in India will become unsustainable.

Thinking at the regional scale is important, with the creation of interconnected clusters (mixed land use development) with last mile connectivity to transit (road, rail and highway for both passenger and freight) necessary. This must be accompanied by improving existing infrastructure and basic amenities, and ensuring timely land availability for such public transport purposes. There is need to think about creation of a multipolis – drawing lessons from the polycentric multipolises of the Rhine Ruhr area in Germany, the Randstad in the Netherlands and the Rhone-Alpes region in France – and other best practices, relevant in the Indian context (Peter & Pain, 2006). This type of connected region, with

* Corresponding author. Department of Civil Engineering, Indian Institute of Science (IISc), Bangalore-560012, Karnataka, India. Tel./fax: +91 80 2293 2329.
E-mail addresses: rsashu@yahoo.com, ashishv@civil.iisc.ernet.in (A. Verma), hs.sudhira@iihs.ac.in, sudhira@gubbilabs.in (H.S. Sudhira), sujaya@cstep.in (S. Rathi), robin@cstep.in (R. King), ndash@civil.iisc.ernet.in (N. Dash).
[1] Tel.: +91 80 4249 0034 (O); fax: +91 80 22372619.
[2] Tel.: +91 80 4249 0034 (O); fax: +91 80 22372619.

0739-8859/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
10.1016/j.retrec.2012.05.013

cities and towns of different sizes, provides a more sustainable and pleasant regional development and urban form compared to megacities. Combined transportation and land use alternatives of all types must be considered.

It is believed that rail transport should be pursued aggressively, and that rail, as a long lived investment, requires both planning ahead for anticipated population and economic growth as well as taking advantage of technological advances. As a result, High Speed Rail (HSR) should be considered. It is argued HSR can play a role in achieving this more balanced and sustainable development of towns and cities, opening up opportunities for growth across a wider, inter-connected, region, with the benefit of taking the pressure of the larger cities to absorb additional burgeoning populations.

This paper will make the case that in the current Indian context, current patterns of megacity growth are unsustainable, and that HSR can play an important role in providing opportunities for medium and smaller size cities through their interconnections. It begins by highlighting the role that railways have played in India and other countries, noting that merely economic analysis of their costs and benefits generally underestimated their contributions to development. It then provides an introduction to HSR and its potential impact in general, before applying this to the example of the State of Karnataka in South India.

2. Railways and development

Without entering the debate about the historical role of the railways in Indian colonial and post-independence, the reach of rail throughout India as a viable travel option for both individuals and goods is an accepted fact. As of the most recently available data of 2007, India has a network of over 63,000 km connecting 6909 stations. In 2006–7, passengers exceeded 6 billion, and almost 700 billion passenger kilometers. Similarly, over 700 million tones and 481 billion net tonne kilometers of freight were transported (Government of India, 2009). Few other systems of the world handle such distances or volumes.

How are the benefits of such connectivity measured? A rich literature exists which discusses such issues, to which we briefly allude. While economic costs are important and must be considered, analysts and policymakers acknowledge that many of the benefits of opening up new opportunities for growth in an environmentally sustainable way are longer-term externalities which traditional cost-benefit analysis tends to overlook and minimize (Haynes et al., 2006; Rietveld et al., 1989; Rietveld & Vickerman, 2003; Shiftan et al., 2002). Indeed, it is these positive externalities which turn the argument in favour of HSR, allowing for the use of new technology to create more sustainable transport and development alternatives.

It is in this context, HSR plays an important role in improving possibilities of medium to small cities, by strengthening their accessibility and connectivity linkages to provide development opportunities. HSR connectivity can help them overcome their traditional isolation from national and international transportation networks, significantly improving their locational advantages, especially of the small and intermediate cities (Ureña, Menerault, & Garmendia, 2009). It is likely to act as a catalyst for economic development. Improvement of locational advantages should help these areas to attract more investments needed to revitalize the nodes connected by the rail link. Recent work shows that a new high speed rail line connection to several smaller towns from Frankfurt and Cologne, resulted in rise in GDP by 2.7 per cent compared to smaller cities not connected by HSR (Ahlfeldt & Feddersen, 2010). However it should be emphasised that individual HSR investments should not be isolated investments but part of a strategic integrated State programme that will deliver statewide regeneration through integration.

3. High speed rail (HSR) as a system

High-speed rail (HSR) is a type of passenger rail transport that operates significantly faster than the normal speed of rail traffic. Specific definitions by the European Union include 200 km/h (120 mph) for upgraded track and 250 km/h (160 mph) or faster for new track. Owing to the overall increase in private vehicle ownership, increasing road infrastructure that fragment the land-use of an urban agglomeration, HSR represents the public mode that transfers passengers and freights from high consumption (roads) to low consumption modes (HSR) in a shorter time and at a comparable speed to air transport.

High speed rail is often viewed as an isolated system and simply as advantageous or disadvantageous as compared to other transport systems, but all transport systems must work together to maximize benefits. A good HSR system has capacity for non-stop and local services and has good connectivity with other transport systems. HSR, like any transport system, is not inherently convenient, fast, clean, nor comfortable. All of this depends on design, implementation, maintenance, operation and funding.

Operational smoothness is often more indicative of organizational discipline than technological prowess. High-speed rail has the advantage over automobiles in that it can accommodate more passengers at speeds far faster than those allowed by car in most countries. The lower limit for HSR (200 km/h, 125 mph) is substantially faster than the highest road speed limit in most countries. Moreover, train tracks permit a far higher throughput of passengers per hour than a road of the same width. A high speed rail needs just a double track railway, one track for each direction. A typical case of 15 trains per hour and 800 passengers per train implies a capacity of 12,000 passengers per hour in each direction. By way of contrast, the Highway Capacity Manual (Highway Capacity Manual, 2000, Transportation Research Board, USA, pp. 13–15) gives a maximum capacity for a single lane of highway of 2250 passenger cars per hour (excluding trucks or RVs) with level of service B which can be summed up to 13,500 passenger cars per hour for a 6-lane highway as in cities with multi-lane divided carriageways connecting Central Business Districts (CBD's) to their suburbs. Assuming an average vehicle occupancy of 1.57 people a standard twin track railway has a typical capacity of 13% greater than a 6-lane highway (3 lanes each way) capacity when compared in same unit, while requiring only 40% of the land (1.0/3.0 versus 2.5/7.5 ha per kilometer of direct/indirect land consumption). This means that typical passenger rail carries 2.83 times as many passengers per hour per meter (width) as a road (High-speed rail, n.d.).

3.1. Accessibility and travel time

HSR implies changes in accessibility and travel time which induce changes in modal share and new transport demands. These are called the "transport" effects of HSR (Givoni, 2006), and are directly based on the space/time relations (Spiekermann & Wegener, 1994). The literature on transport effects of HSR has focused on accessibility and modal share changes (Fröidh, 2005; Gutierrez, 2001; Vickerman, 1997; Willigers, Floor, & Van Wee, 2007) and on new mobility patterns, characterizing passengers and inter-city relationships (Klein & Claisse, 1997; Klein & Million, 2005; Menendez, Coronado, & Rivas, 2002; Ribalaygua, Sánchez, Coronado, Garmendia, & Ureña, 2006). The latter has focused on metropolitan integration processes and new commuting patterns (Garmendia, Ureña, Ribalaygua, Leal, & Coronado, 2008), trying to shed light on the "uneasy" relationship between mobility and spatial dynamics (Priemus, Nijkamp, & Banister, 2001).

3.2. Urban function

The HSR connection will optimize the function structure and provide additional opportunities for both the existing industries in the medium sized cities and new ones. The impacts of the investments on HSR supply and demand should not be underestimated, especially when strategically integrated with the overall development of the network to improve stations, station areas and feeder services. HSR related reduction of travel time is likely to enhance passenger ridership, inducing development of trade, logistics, etc, thus forming an urban networked structure that has distinctive functions that are inter-connected to each other.

4. Factors influencing HSR impacts

The HSR urban role is related to the double identity of the stations established by Bertolini and Spit (1998): a transport node and a place. The HSR station may become the city gate, improving the integration of the station area with the rest of the city (Mannone, 1997) and with other HSR cities (Garmendia et al., 2008). Furthermore, each scale (station surroundings, local, regional, national or international) interacts and influences the other ones (Ureña et al., 2009). In the literature, many note that HSR almost never generates anything new but rather accelerates or consolidates existing dynamics and strategies (Givoni, 2006; Offner, 1993; Plassard, 1990) and highlights the necessity of strategies to maximize the HSR benefits and dim its negative effects (Bazin, Beckerich, & Delaplace, 2006; Van Den Berg & Pol, 1997). Given the different characteristics of cities, HSR networks, and regional/national contexts, there is no recipe to ensure success, but empirical studies comparing the effects on various case studies leads to a set of general criteria. These criteria can be synthesized in two spatial factors in order to understand the roles and challenges of HSR: the territorial and infrastructural factors and the city or agglomeration ones.

The territorial and infrastructural factors are:

- The HSR cities location in relation to metropolises. Travel time is a key factor (Klein, 2004), as depending on it HSR allows the appearance or consolidation of certain inter-urban relations such as commuting in 1 h (Fröidh, 2005; Klein & Claisse, 1997) and business often day return travel in 2–3.5 h (Ureña et al., 2009).
- The previous and present relations to the main transport corridors and nodes. In some cases the HSR means a substantial change in location advantages, while in others it only consolidates them (Menerault, 1998; Ureña et al., 2009).
- City location on the HSR infrastructure (intermediate vs. end, through vs. crossing) determine the possible inter-urban connections and services (Auphan, 2002) and the station location within each city (Klein & Million, 2005).
- Travel time and infrastructure layout are the most relevant factors to infer HSR spatial implications as they are more permanent than other general transport cost factors (fares, frequency, service quality) which are modified frequently. However, some authors consider frequency of service, schedule and destinations as important as having an HSR station (Rabin, 2004).

The city or agglomeration factors are:

- Each city's economic base. Tertiary cities present more synergies with HSR than industrial ones (; Burmeister & Colletis-Wahl, 1996)
- The existence of administrative, office and singular services: regional capitals, business headquarters or universities (Kobayashi & Okumura, 1997).
- The quality of public and private services (Ureña, Coronado, Escobedo, Ribalaygua, & Garmendia, 2006), environment and cultural qualities (Troin, 1995).
- Their local entrepreneurship environment (Bellet, Alonso, & Casellas, 2010; Van Den Berg & Pol, 1997).

If some of these features are combined with custom-made local or regional strategies, and an adequate sitting of the station, they would be synergic to the HSR. This view considers HSR as a necessary, though not sufficient condition, for sustainable and positive economic and urban dynamics. Thus incorporating HSR anywhere requires studying the population density in each region of interest, conducting an intensive survey to establish the need of commuters in terms of distance and travel time. This would help to obtain comparative study on different operation modes in the area and what difference would HSR bring to it in terms of the aforesaid factors. An intensive study of the areas in terms of passengers, existing modes and their travel time that need to be connected to each other as well as to major cities (Bangalore, in the case in question in this paper) would help in developing an optimized route that could cater shorter period travel yet with larger target areas. It would also help in integrating HSR with other modes to provide better dynamics to the transport infrastructure. Apart from its physical integration HSR displays a better sustainable future in comparison to conventional rail.

5. Possible impacts of HSR–case of Karnataka and the region

5.1. Dynamics of city-size distributions

The evolution of towns into cities and urban agglomerations raises interest in exploring any possible underlying pattern in the course of ongoing urbanization. The hierarchical organisation of societies (towns and cities) by their city-size distributions confirming to some of the scaling laws as in biological systems, has been well studied. There is already considerable treatment on the applicability of scaling laws in urban systems and ranking of the organisation of societies (Batty, 2008; Fujita, Krugman, & Venables, 1999; Gabaix, 1999; Gabaix & Ioannides, 2003; Pumain, Saint-Julien, & Sanders, 1986). Recently, Bettencourt, Lobo, Strumsky, and West (2010) have extended the scaling laws to develop a new class of metrics by applying them to wealth, innovation and crime across cities in the United States.

Bangalore is the principal administrative, cultural, commercial, industrial, and knowledge capital of the state of Karnataka, India. It has been identified as the country's 'Silicon Valley' and it is one of the technological innovation hubs with a score of 13 out of a maximum of 16[3] (United Nations Development Programme, 2001). However, with all the hype about growth in IT and IT based industries, Bangalore also houses numerous other leading commercial and educational institutions, and industries like textiles, aviation, space, biotechnology, etc. As an immediate consequence of this growth in the last decade, apart from creating

[3] Almost on par with San Francisco (USA), while Silicon Valley (USA) is number 1 with a score of 16.

a ripple effect in the regional and local economy, there has also been great pressure on infrastructure and resources like water supply, energy, public transportation, land, etc. Of late, the development and growth in Karnataka has been concentrated in and around Bangalore due to various reasons, a prominent one is its much better connectivity to other parts of the country as compared to other tier-II cities of the state and lack of fast connectivity from Bangalore to tier-II cities.

5.1.1. Zipf's law

One of the intriguing empirical facts in social sciences and economics is Zipf's law for cities. Zipf had noted the regularity as an inverse geometric progression between the population P_i of a city and its rank R_i in a national set of towns and cities, giving an approximate size of one half of the largest city population for the population of the second city and one third for the third one, and so on. This "rank size-rule" formulated as $P_i = P_1/R_i$ has been generalised as a Pareto-type distribution of the number of cities according to their size, $P_i = K/R_i\ \alpha$, where the parameter K has a value close to P_1 and α is around 1.

From the available literature, it is now evident that this model has been fitted many times to more or less correctly measured population series of towns and cities. Typically, the estimated value for the parameter ranges between 0.7 and 1.3 for the population of the urban agglomerations (towns and cities over 10,000 inhabitants) of each state in the world. Pumain (2004) remarks on the ill-founded conclusions based on Zipf's law mainly due to small samples of observations and a lack of accuracy in empirical data. However, Fletscher (1986, In: Pumain, 2004) has demonstrated based on the data for early settlements that whatever the part of the world and the period of observation, for last 10,000 years when towns first emerged, the model of settlement size distribution have always been reasonably well approximated by a Pareto or log-normal distribution. Pumain (2004) further notes that often, the upper part of the size distribution, corresponding to the largest urban settlements, does not fit very well to any model. These cases of urban primacy (one to up to eight cities per state whose size exceeds the expected values) seem to be a generality rather than an exception. When this 'primacy index' is computed, as the ratio between the population of the largest and second largest city, it is found that in most states of the world it is much larger than the value of two, which would correspond to Zipf's rank size rule and the mean value for all countries of the world taken together is 5.2. The confirmation to the rank-size model (Zipf's law) is also true for the top cities in India, almost mysteriously, similar to most other nations of the world (Pumain, 2004).

The Zipf's law or the rank-size rule states that when logarithm of ranks and corresponding city sizes are plotted on a log–log plot, they would fit a straight line. In other words,

Table 1
Estimates for rank-size distribution model to towns and cities of Karnataka.

Year	α	R^2	P_k	P_1
1901	0.83	0.93	177,976	163,091
1911	0.85	0.92	181,396	189,485
1921	0.85	0.95	209,419	240,054
1931	0.85	0.96	243,477	309,785
1941	0.88	0.95	333,558	410,967
1951	0.87	0.97	462,989	786,343
1961	0.90	0.97	619,737	1,206,961
1971	0.92	0.94	895,520	1,664,208
1981	0.93	0.98	1,294,733	2,921,751
1991	0.96	0.98	1,812,023	4,130,288
2001	1.04	0.94	3,002,970	5,686,844

Note: P_k is the estimate of the population for the city with rank 1 (P_1).

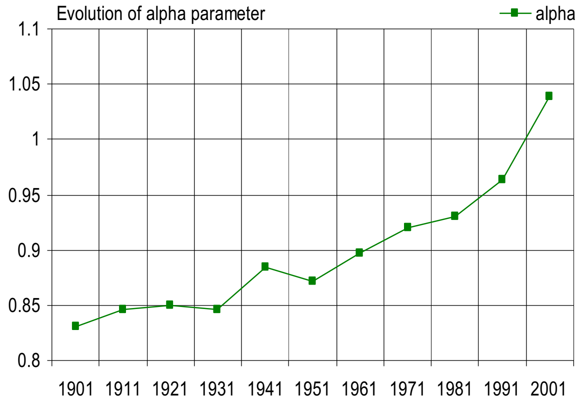

Fig. 1. Evolution of alpha parameter for towns and cities in Karnataka.

$$\ln(rank) = P_k - \alpha \ln(\text{city size}) \quad (1)$$

with high R^2, where P_k is the population of the city with highest population (Gabaix, 1999).

5.1.1.1. Validation of Zipf's law. An attempt to analyse the city-size distribution of towns and cities in Karnataka was made to validate the Zipf's law. The State of Karnataka is one of the most urbanized states in India with 34 percent urban population. The analysis was carried out for the duration of 1901–2001, decadal census data.[4] The model is estimated through the least squares method. Accordingly, the model was estimated in the form of Equation (1), which indeed revealed a high R^2 and increasing α (Table 1).

The analysis conforms to the Zipf's law, similar to other empirical studies pertaining to other nations and verifies the prevalence of characteristic scaling behaviour in urban systems (Gabaix, 1999). Gabaix (1999) and Pumain (2004) have separately offered explanations for the presence of scaling effects in urban systems, yet, the implications from scaling behaviour with respect to the organisation of human societies in structurally similar pattern as observed in different places irrespective of their geographic boundaries, political boundaries and political economies raises many questions.

Pumain (2004) asserts that the general structure of urban systems, including scaling effects is the result of social evolutionary processes: as in biological sciences, but in this case the evolution is also partly driven by a cognitive activity of inventing technical and social artefacts. However, the action of this organizing principle on the spatial structure of the urban systems is almost always indirect: especially at the level of the system of cities, as there is neither conscious nor responsible institution for organizing and adapting the system to ensure this increasing power of accessibility. The global structure and its more or less continuous adaptation are emerging from the inter-urban competition.

It is intriguing to note that Bangalore (5,686,844) which emerged as the largest city had taken the lead by almost 8 times from its nearest contenders (Hubli-Dharwad with 786,018 and Mysore with 785,800) [based on 2001 Census estimates]. The evolving primacy index (Fig. 1) is a cause of concern in the State of Karnataka indicating the increasing urban hierarchy.

The analysis clearly indicates the magnitude of concentrated growth and a strong urban primacy (since $\alpha > 1$), a consequence of accelerated growth of Bangalore alone in the state vis-à-vis other

[4] The Census 2011 data for all cities is yet to be available and so the Zipf's law analysis cannot be performed for 1901–2011, at this point.

cities of the state. The situation has been alarming evidently since the last decade with $\alpha > 1$. Thus it is essential for state to intervene at certain level to ensure distributed growth.

5.1.2. Comparison of modes

Redistribution of growth: Implementation of HSR technology in Karnataka would mean a redistribution of growth and development to areas that otherwise consume comparatively more time to travel by conventional means. Fig. 2 shows the existing rail network in Karnataka. Directly it would contribute to a sustainable form of transport in integration with other modes, promote better land-use development, encourage development of tier-II cities in Karnataka, discourage unnecessary road expansion that adds to physical carbon footprint, reduce road use that contributes to transport carbon footprint. Indirectly it would contribute to reduction of fuels that feed private vehicles and buses, decongest the Bangalore city reducing the burden on consumption of resources of the city. The concentric pattern of Bangalore could be used as an advantage to develop HSR to serve at both the regional and inter-urban level. The same stations could be developed to serve as common platform for HSR and other public modes at places where it is difficult to spread track lines. This could encourage expanding the same station for dual usage instead of building separate stations and track lines for the new HSR, further improving the economics of multiple modes and their coordination.

Time-savings: Inter-city buses cater to near-by towns. Bus service is often slow, and contributes to congestion along roads

Fig. 2. Existing railway network in Karnataka.

within Karnataka and in the outskirts and within cities such as Bangalore. Rail corridors serve satellite towns like Tumkur, Chikballapur, Bangarapet, Hosur and Mandya via commuter trains that run in morning and evening to reach the desired location ranging from 1 to 3 h. Any choice to provide air traffic would induce a high infrastructure cost and high land consumption. In contrast High Speed Rails provide a better solution in terms of balancing travel time (and hence speed) and the infrastructure needed to run it. Also as passenger capacity is higher than other road based modes, high speed rail can be looked upon as an alternative option to reduce dense corridors created by other modes of public transport.

To cite an example, Mysore is located 130 km and 140 km by flight and road distance respectively, from Bangalore. Considering average speed of commercial flight at 500 km/h it would take approximately 15 min (flying time only) to reach Mysore and 160 min by road considering the average bus speed to be 52 km/h. However road congestion can hamper the calculated travel time and hence cause delay. On the other hand air transport is infeasible at such small distance together with heavy cost involved to support it. Hence HSR can be considered a viable option to bus and air mode with a travelling speed of 200–250 km/h and reaching the destination in 35–45 min, respectively. Also the advantage it has over previous modes is that it can have stoppage at different stations at a comparatively shorter time.

However success of HSR cannot be seen in isolation; its success depends on integration and planned operation and maintenance along with other modes. Although jet travel has speed advantage with multiple boarding points, trains can be boarded more quickly and stations located closer to if not within urban centres. This can mostly offset the speed advantage of jet travel for mid-distance trips. Other advantageous points for HSR over air travel could be weather, comfort and large number of target areas. HSR could permit far greater capacity and frequency of service than what is possible to bus or air travel considering time and distance as key factors. Although comfort is considered a trait for air travel, it is not inherent. Rail travel could accommodate standing passengers as well. Larger target areas in shorter time span can be accomplished in an HSR than conventional rail or airplane. Apart from these, HSR have better energy efficiency and are safer over air/bus travel. A comparison of distance and travel time for road, rail (conventional rail), air and HSR for various major headquarters of Karnataka from Bangalore is included in the Annexure 1. It is observed that HSR would take 20% of the time taken by conventional train.

Considering these comparable advantages of HSR over other modes, HSR can be considered as a forward looking option to connect satellite towns of Karnataka to its IT hub at Bangalore, and perhaps as a base for connection to other cities in other states in South India. In the short term, HSR could enable more sustainable patterns and growth in commuting, business and recreation travel in the region. Increase in travel and economic growth due to labour and service markets being extended along the link could in the medium and long term encourage households to move instead of commuting, and firms may also likewise choose to relocate. Connectivity and economic development in tandem would enable better socio-economic integration of the region, as seen in several medium-sized cities in Catalonia with Barcelona, Spain (Feliu, 2007). This could spread out the population density, balance the growth of the state and yet connect them in a close knit network that allows for multiple possibilities.

Apart from short and medium distance, long distance travel (e.g., distance of satellite towns from major cities) can be best served by HSR. Advantages, in addition to a higher speed of 200 to over 250 km/h are comparable to the airplane on distances up to 500 km. These trains can take steeper hills, which may make this option more attractive in hilly areas or places with elevation as certain areas in and around Bangalore, the key nodal city in the case of Karnataka. The acceleration power is higher too, which make this train more attractive at smaller distances.

Environmental Factors: Another advantage is that the space claim of the infrastructure is somewhat smaller. These contribute to a reduction of the emissions of greenhouse gases in comparison to road or air modes with a greater passenger capacity per hour. Thus HSR can be seen as a better option to these modes when considering the environmental effect, cost involved in developing the infrastructure which is permanent in case of HSR and is variable over years for the previously discussed modes and the ratio of land consumption is least in case of HSR.

Comparison between HSR and Conventional rail can be sought through following parameters

I. *Per-passenger km (pkm)*: HSR is anticipated to produce lower GHG emissions than Conventional Rails. On average, HSR (at 30.3 g CO_2eq/pkm) is expected to result in around 15% less GHG emission than conventional rail (at 35.7 g CO_2eq/pkm) in 2025 according to calculations using central values. This GHG emissions for HSR reduce further to 18.8% less (at 18.5 g CO_2eq/pkm) than conventional rail (at 22.7 g CO_2eq/pkm) when considering them over 30-year lifetime of the train.
II. *Sensitivity Analysis of Occupancy levels and Passenger Numbers*: The average passenger occupancy levels are approximately same for HSR and Conventional rails. Parity is reached in their relative emissions when load factors for Conventional rails are around 4% lower than those for HSRs. However it is the total passenger number that plays critical role in the analysis as this affects the allocation of emissions resulting from rail infrastructure. Therefore a higher number of services with lower occupancy but high overall passenger numbers is strongly favoured over significantly less-frequent but high-occupancy services that potentially move fewer passengers.
III. *Impact of Electricity De-carbonization*: When assuming electricity emission factors and electric train models the GHG emissions due to direct energy use of the train accounted for over 80% of total emission (with 18% due to rail infrastructure and $<$1% due to indirect emission by trains). Emission from new rail construction account for 70% of total emission. Majority of emission from construction of new rail comes from use of steel and concrete. Significant gains could be achieved by focussing on reducing the emission footprints from these materials.

Thus the overall analysis has demonstrated significant net benefit of HSR services over equivalent Conventional rail services in terms of energy consumption and GHG emissions per passenger-km in context of the proposed HSR technology. Also highlighted are the significant GHG emissions due to new rail infrastructure in the anticipated future when electricity generation is de-carbonised. This in turn puts significant emphasis on importance of minimizing emissions from the construction of any new rail infrastructure focussing on sourcing low carbon materials and on recyclability of end life components. On basis of this, development of new lines to provide HSR services appears to be highly desirable in reducing GHG emissions at a long term. However there will be significant upfront GHG emissions from construction of new infrastructure in short term.

5.1.3. Economic development

According to the London School of Economics and Political Science and the University of Hamburg research, towns connected to a new high-speed line saw their GDP rise by at least 2.7 per cent compared to neighbours not on the route. Their study also found that increased market access through high-speed rail has a direct correlation with a rise in GDP – for each one per cent increase in market access, there is a 0.25 per cent rise in GDP. Their research focused on the line between Cologne and Frankfurt, which opened in 2002 and runs trains at almost 185 mph (300 kmh). The authors looked at the prosperity and growth of two towns with stations on the new line – Limburg and Montabaur – and compared them with more than 3000 other municipalities in the surrounding regions. Other case studies in Europe indicate that linkages to HSR has either directly or through a connecting service provided a catalyst for urban development and has contributed to the economic development of the city and/or region. In fact, particular cities that are connected directly to the HSR network, feel that they have improved their economic position on a regional or even national scale. Evidence from Maastricht suggest that cities that are on or closely connected to the HSR network are easier and faster to reach from different parts of Europe and this has the potential to have a positive impact on many aspects of the economy (HST Impact Study Consortium, 2008). Another benefit of an HSR buildout given the current economic slowdown would be to spend government spending, into regions often bypassed. Even recent research that is critical of overall government spending during the US New Deal has shown beneficial local effects of public works expenditures in this period (Fishback, Horrace, & Kantor, 2004).

5.1.4. Creation of polycentric metropolises

New accessibility can impact significant changes to a region. In the short term, HSR may allow a growth in commuting, business and recreation travels between the urban systems. Increase in travel intensity and economic growth stimulated due to the labour and service markets being extended along the link may in the medium and long term, encourage households to move instead of commuting, and that certain groups of firms may also likewise choose to relocate from the primary city. The

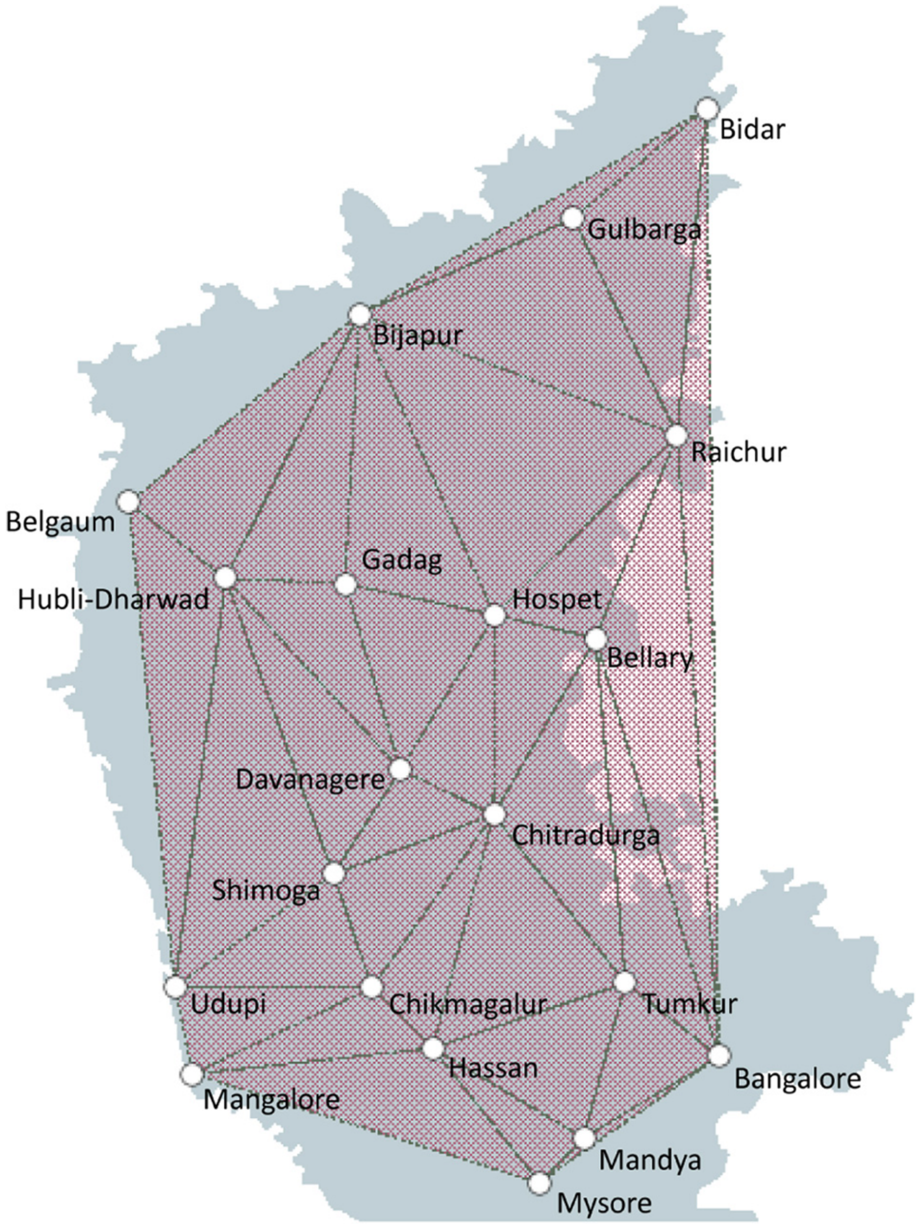

Fig. 3. Delaunay triangulation for cities in Karnataka.

enhancement of accessibility and connectivity between the nodes on the rail link and also the development of economic systems may allow for better socio-economic integration of the region, as in the case of several medium sized cities in Catalonia with Barcelona, Spain-initiation of the development of a polycentric region (Feliu, 2007). As seen in the case studies of Paris, Brussels, Cologne, Amsterdam and London, there are clear improvements for transport and mobility in relation to the strategic HSR network linking (HST Impact Study Consortium, 2008). Nearly all the case study sites do benefit in terms of increased HSR services and feeder services and a resulting reduction of travel times.

In the case of India, there is an urgent need for revitalization of smaller cities and towns to make urbanization sustainable. Larger megacities simply cannot accommodate the quantities of rural migrants expected (in fact, they are struggling to meet the current loads). Thus, one needs to think of creating a 'multipolis', drawing lessons from the polycentric multipolises of the Rhine Ruhr area/ Randstad, Holland, and other such best practices, adopting and adapting them for Indian reality (Peter & Pain, 2006). For example, HSR connection along the Bangalore Mysore Corridor, will strengthen economic and social ties between cities like Bidadi, Ramanagaram, Channapatna and Mysore, along the railway link. This will help upgrade the infrastructure and connectivity in these medium sized cities in the region to help them establish themselves in leading roles in the urban system. The reduced travel time and improved connection to these cities will provide impetus towards spatial integration. Furthermore, with strategic and

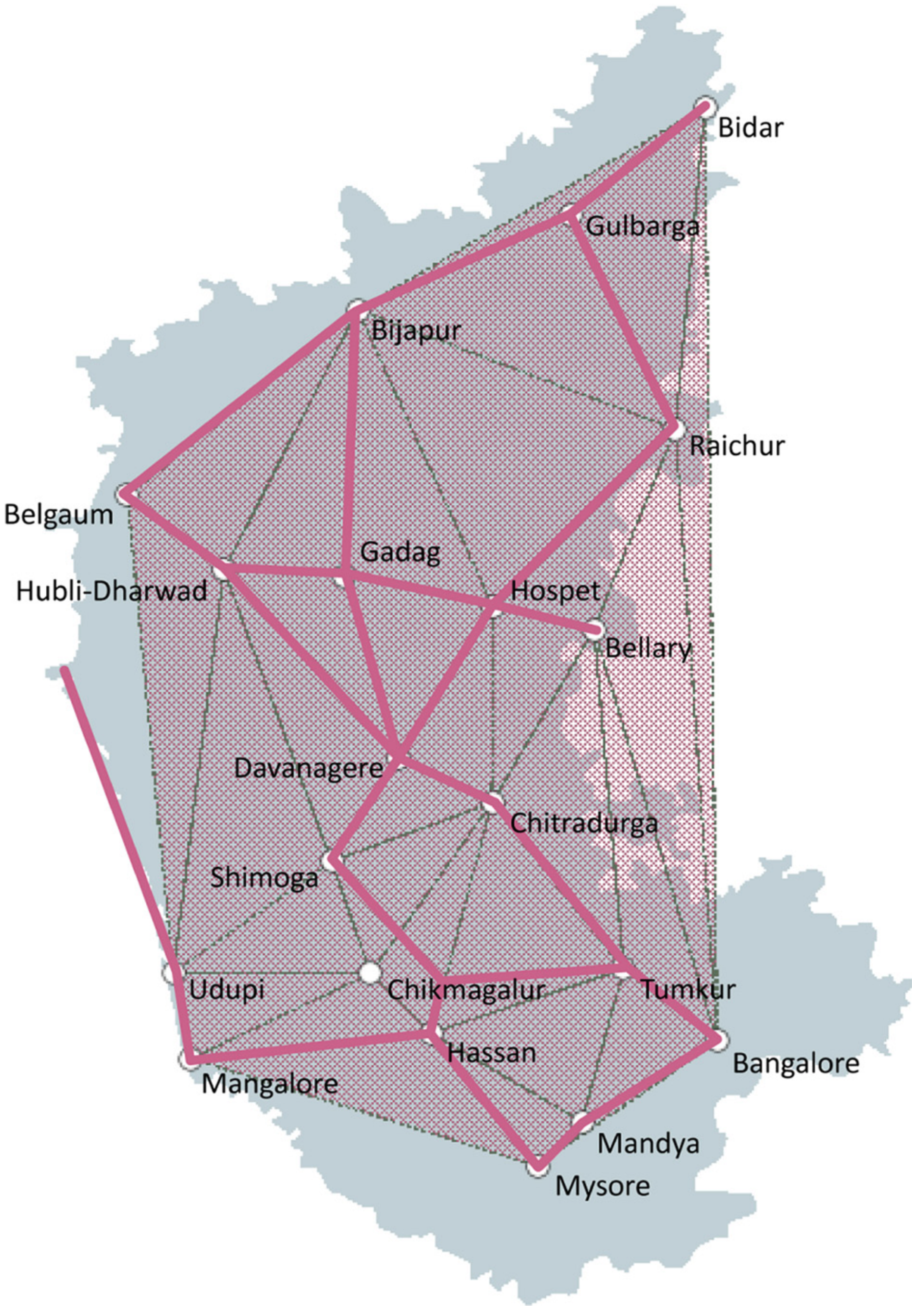

Fig. 4. Proposed HSR corridors.

comprehensive planning accessibility of stations can be improved by creating new or improved feeder services to the primary HSR network. These improvements not only make the facility itself stronger but also increase the catchment area for travellers and commuters alike.

While the authors are aware the argument here is based on cases rather than a quantitative technique, they would point to evidence that many of the quantitative techniques traditionally used have been shown to inadequately capture benefits, and thus the use of cases represent a next best alternative (Vickerman, 2007).

The primacy of the megacities (in this case Bangalore) and also other regions in India is a key argument to consider and implement HSR to spatially balance economic and urban development. International experience supports this view. In Lyon, the high speed rail link to Paris has enabled firms from the city to benefit from improved access to the French capital. The area around Lyon's Part Dieu high speed rail station now hosts 5.3 million square feet of office space and around 20,000 jobs. Similar patterns have been observed in Japan, where high speed rail has seen a dispersal of investment and economic activity from the main 'developed region' towards the periphery. And in Spain, a number of towns and cities have benefited from improved links to the capital – for example, Lleida, whose high speed rail links have helped to attract investment from Microsoft and other high-tech companies. HSR plays an important role in rebalancing the economy spatially. However, HSR strategy need to be implemented in tandem with regional urban development strategy requires identifying small cities and towns as growth centers, linked together into networks and corridors. Also, in the backdrop of rising fuel prices, environmental concerns and road congestion, India should consider HSR, as was done in the 1960s in Europe.

5.2. *Existing and proposed corridors*

The railway network in Karnataka falls largely under South Western Railways and Konkan Railways divisions of the Indian.

Railways. Based on the existing tracks (Fig. 2), the following are the prominent connections and junctions:

- Bangalore – Mysore
- Bangalore – Arsikere – Hassan – Mangalore
- Mangalore – Hassan – Mysore
- Mangalore – Udupi – Karwar
- Bangalore – Birur – Davanagere – Hubli
- Bangalore – Birur – Shimoga
- Hubli – Dharwad – Belgaum
- Hubli – Gadag – Bijapur – Gulbarga
- Hubli – Gadag – Hospet – Bellary
- Bangalore – Guntakal – Bellary
- Bangalore – Guntakal – Gulbarga

The map depicts the existing railway networks and important cities of Karnataka. Although the existing connections are spread across the state, there are some key missing links that are evident from the map. Notable among them are: Tumkur – Chitradurga/Davanagere – Bellary; Hassan – Chikmagalur; Shimoga – Davanagere; and Belgaum – Bijapur. At present, Hassan – Chikmagalur is approved while a feasibility study for Tumkur – Chitradurga is pending.

Further, in order to ascertain the minimum spanning tree for these cities (considering these cities as points on Euclidean space), Delaunay triangulation (detailed in Annexure 2) is used to derive the potential network (Fig. 3). From practical understanding and geographical constraints, the following are the proposed HSR corridors (Fig. 4), however a detailed feasibility study is required to finalize the HSR corridors:

- Bangalore – Tumkur – Chitradurga – Davanagere – Hubli – Dharwad – Belgaum
- Bangalore – Mandya – Mysore
- Bangalore – Tumkur – Arsikere – Birur – Shimoga – Davanagere
- Arsikere – Hassan – Mangalore
- Hassan – Mysore
- Davanagere – Hospet – Raichur – Gulbarga
- Belgaum – Bijapur – Gulbarga – Bidar
- Hubli – Gadag – Hospet – Bellary
- Davanagere – Gadag – Bijapur
- Mangalore – Udupi – Karwar

Ideally, it may be worthwhile to connect Udupi with Chikmagalur or Shimoga, the Western Ghats poses practical challenges. The same challenges exist for connecting Karwar with either Hubli – Dharwad or Belgaum.

Cost Estimates were not done given the difficulty of accurately estimating projects of this magnitude, especially with uncertainty prevailing on land costs. Most mega-projects have historically run into cost overruns: Suez Canal 1–900%, Panama Canal – 200%, Brooklyn Bridge – 100%, Channel Tunnel – 80% (Flyvbjerg, Bruzelius, & Rothengatter, 2003). Even in India, the Delhi Metro Phase I had a cost overrun of 117% (The Business Line, India, 2005).

6. Conclusion

Experience with HSR services around the world shows that the most relevant inter-urban spatial implications of HSR take place in medium size and small cities where HSR has produced major changes in accessibility. On the other hand, the station location is playing key roles HSR effects on urban agglomeration. Decisions of whether a station will be central or peripheral is usually related to a balance between infrastructure/service benefits and urban/social ones: shorter HSR lines between metropolises and thus peripheral stations in intermediate cities or longer HSR lines with more detours to reach central places of intermediate cities. HSR station location is crucial for small cities because they often have peripheral HSR stations unconnected to traditional rail, while in big cities central combined stations are more frequent. HSR can increase the opportunities for big intermediate cities to play greater roles in the national system of cities, and for small cities to interact with metropolises up to 1 h HSR travel time and with other distant small cities and for previously isolated areas to become transportation nodes. Better results can be obtained by combining HSR layout national criteria (minimum distances, fewer stops, etc) with the local ones (proximity and more connections). With different spatial models (settlement system and demographic density) and patterns (travel behaviour, commuting distances) HSR can prove to be the most useful polarized urban networks.

It is critical to note that investments on HSR only will not have any measurable impact if it is not accompanied by a regional strategy for decongesting megacities. Alleviating excessively high urban concentration requires investments in interregional transport and telecommunications to facilitate deflection of economic activities from the megacities. It also requires fiscal decentralization, so that smaller cities can reach out to fiscal resources and provide services needed to compete with the megacities for industry and population. Redistribution of investment is recommended to develop a strong economic base for small and medium cities which have been neglected so far, so that migration flows are directed towards them.

Annexure 1

District headquarters	Drive distance (Km)	Drive time (hours)	Flight distance (Km)	Flight time (hours)	Train distance (Km)	Train time (hours)	Time with proposed HSR (hours)
Bagalkot	473	7.33	408	0.500	615	12.71	2.46
Belgaum	505	7.40	461	0.560	619	11.66	2.47
Bidar	621	9.35	544	0.680	730	15.66	2.92
Bijapur	529	8.13	472	0.580	712	15.08	2.80
Bellary	308	4.40	250	0.316	327	7.75	1.31
Chamrajnagar	185	3.32	137	0.167	199	–	–
Chikmagalur	240	4.13	199	0.250	–	–	–
Chitradurga	201	3.05	188	0.240	–	–	–
Gadag	377	6.32	343	0.434	500	11.0	2.00
Gulbarga	623	9.35	488	0.600	585	11.65	2.34
Hassan	182	3.30	161	0.200	265	5.00	1.06
Hosur	45.0	0.78	39.0	3.000	60.0	1.08	0.24
Haveri	334	5.00	310	0.400	392	7.00	1.60
Dharwad	405	5.98	370	0.470	498	9.00	2.00
Karwar	519	8.20	425	0.54	–	–	–
Kolar	68.0	1.36	62	0.10	–	–	–
Koppal	355	5.53	304	0.40	452	10.4	1.8
Madikeri	258	4.88	210	0.30	–	–	–
Mandya	101	2.00	90.0	0.12	99.0	1.75	1.75
Mangalore	348	6.18	299	0.36	510	12.0	2.04
Mysore	140	3.00	130	0.20	144	3.08	0.57
Raichur	462	6.43	357	0.45	420	8.66	1.68
Shimoga	277	4.63	241	0.30	272	6.00	1.088
Tumkur	70.0	1.23	66.0	0.10	64.0	1.00	0.25
Udupi	397	6.85	310	0.40	–	–	–

Annexure 2

Delaunay triangulation

A Delaunay triangulation for a set P of points in a plane is a triangulation DT(P) such that no point in P is inside the circumcircle of any triangle in DT(P). Delaunay triangulations maximize the minimum angle of all the angles of the triangles in the triangulation; they tend to avoid skinny triangles. For a set P of points in the (d-dimensional) Euclidean space, a Delaunay triangulation is a triangulation DT(P) such that no point in P is inside the circum-hypersphere of any simplex in DT(P). It is known[2] that there exists a unique Delaunay triangulation for P, if P is a set of points in general position; that is, there exists no k-flat containing $k + 2$ points nor a k-sphere containing $k + 3$ points, for $1 \le k \le d - 1$ (e.g., for a set of points in $\mathbb{R}3$; no three points are on a line, no four on a plane, no four are on a circle, and no five on a sphere).

The problem of finding the Delaunay triangulation of a set of points in d-dimensional Euclidean space can be converted to the problem of finding the convex hull of a set of points in $(d + 1)$-dimensional space, by giving each point p an extra coordinate equal to $|p|2$, taking the bottom side of the convex hull, and mapping back to d-dimensional space by deleting the last coordinate. As the convex hull is unique, so is the triangulation, assuming all facets of the convex hull are simplices.

Non-simplicial facets only occur when $d + 2$ of the original points lie on the same d-hypersphere, i.e., the points are not in general position (Delaunay Triangulation, n.d.).

References

Ahlfeldt, G. M., & Feddersen A. (2010). From periphery to core: economic adjustments to high speed rail. London School of Economics & University of Hamburg. (Unpublished).

Auphan, E. (2002). Le TGV Mediterranée: un pas decisif dans l'évolution du modèle francais à grande vitesse. *Mediterranée*, (1/2), 19–26.

Batty, M. (2008). The size, scale, and shape of cities. *Science, 319*, 769–771.

Bazin, S., Beckerich, C., & Delaplace, M. (2006). La LGV Est-Européenne en Champagne-Ardenne: quels effets sur la cohésion territoriale champardennaise? [The eastern France European high speed railway in Champagne-Ardenne: which effects on territorial cohesion in Champagne-Ardenne?]. *Revue d'Économie Régionale & Urbaine, 2*, 245–261.

Bellet, C., Alonso, P., & Casellas, A. (2010). Infraestructuras de transporte y territorio. Los efectos estructurantes de la llegada del tren de alta velocidad en España. *Boletín de la Asociación de Geógrafos Españoles*, (52), 143–163.

Bertolini, & Spit. (1998). *Cities on rails. The redevelopment of railway station areas*. London: E&FN Spoon.

Bettencourt, L. M. A., Lobo, J., Strumsky, D., & West, G. B. (2010). Urban scaling and its deviations: revealing the structure of wealth, innovation and crime across cities. *PLoS ONE, 5*(11), e13541.

Burmeister, A., & Colletis-Wahl, K. (1996). TGV et fonctions tertiaires: grande vitesse et entreprises de service à Lille et Valenciennes. *Transports Urbains, 93*, 11–16.

Delaunay Triangulation. (n.d.). In *Wikipedia*. Retrieved November 30, 2011, from http://en.wikipedia.org/wiki/Delaunay_triangulation.

Feliu, J. (2007). *HST and polycentric regional development of Catalonia*. Unitat de Geografia, Universitat de Girona.

Fishback, P. V., Horrace, W. C., & Kantor, S. (February 2004). *Did new deals grant programs stimulate local economies? A study of federal grants and retail sales during the great depression*. NBER Working Paper W8108.

Fletscher, R. (1986). Settlement in archaeology: world-wide comparison. *World Archaeology, 18*(1), 59–83.

Flyvbjerg, B., Bruzelius, N., & Rothengatter, W. (2003). *Megaprojects and risk: An anatomy of ambition*. Cambridge: Cambridge University Press.

Fröidh, O. (2005). Market effects of regional high-speed trains on the Svealand line. *Journal of Transport Geography, 13*, 352–361.

Fujita, M., Krugman, P., & Venables, A. (1999). *The spatial economy: Cities, regions and the international trade*. Cambridge, USA: MIT Press.

Gabaix, X. (1999). Zipf's law for cities: an explanation. *The Quarterly Journal of Economics*, 739–767.

Gabaix, X., & Ioannides, Y. M. (2003). The evolution of city size distributions. In J. V. Henderson, & J. Francois (Eds.), *Handbook of urban and regional economics. Cities and geography, Vol. IV*. Amsterdam, The Netherlands: North-Holland Publishing Company.

Garmendia, M., de Ureña, J. M., Ribalaygua, C., Leal, J., & Coronado, J. M. (2008). Urban residential development in isolated small cities that are partially integrated in metropolitan areas by high speed train. *European Urban and Regional Studies, 15*(3), 265–280.

Givoni, M. (2006). Development and impact of the modern high-speed train: a Review. *Transport Reviews, 26*(5), 593–611.

Government of India. (March 31, 2009). Railways. In National Portal Content Management Team. (Ed.). At. India.gov.in/sector/transport/railways.php Accessed 17.03.11.
Gutierrez, J. (2001). Location, economic potential and daily accessibility: an analysis of the accessibility impact of the high-speed line Madrid-Barcelona-French border. *Journal of Transport Geography, 9*(4), 229–242.
Haynes, K. E., Nijkamp, P., Duivesteijn, A., De Jong, H., Schouw, G., & Kuijpers, C. (December 2006). *Megacities lecture 9: Infrastructure: The glue of megacities*. www.megacities.nl Accessed 28.03.11.
High-speed rail. (n.d.). In *Wikipedia*. Retrieved November 10, 2011, from http://en.wikipedia.org/wiki/High-speed_rail.
Highway Capacity Manual. (2000). Transportation Research Board, National Research Council, USA, 13.
HST impact study-final report, HST Impact Study Consortium, version 15th April 2008.
Klein, O. (2004). Social perception of time, distance and high-speed transportation. *Time and Society, 13*(2–3), 245–263.
Klein, O., & Claisse, G. (1997). *Le TGV-Atlantique: entre récession et concurrence – Evolution de la mobilité et mise en service du TGV-Atlantique: analyse des enquêtes réalisées en septembre 1989 et septembre 1993, Colection Études et Recherches: 7.* Lyon: Laboratoire d'Économie des Transports du CNRS.
Klein, O., & Million, F. (2005). *La grande vitesse ferroviaire, le développement socio-économique et l'aménagement des territoires: étude bibliographique et analyse des expériences passées*. Direction Départementale de l'Equipement de la Charente.
Kobayashi, & Okumura. (1997). The growth of city systems with high speed railway system. *The Annals of Regional Science, 31*, 39–56.
McKinsey Global Institute. (April 2010). *India's urban awakening: Building inclusive cities, sustaining economic growth*. McKinsey Global Institute.
Mannone, V. (1997). Gares TGV et nouvelles dynamiques urbaines en centre ville: Le cas des villes desservies par le TGV Sud-Est. *Les Cahiers Scientifiques du Transport, 31*, 71–97.
Menendez, J. M., Coronado, J. M., & Rivas, A. (2002). El AVE en Ciudad Real y Puertollano. Notas sobre su incidencia en la movilidad y en el territorio. *Cuadernos de Ingeniería y Territorio* (2), Universidad de Castilla La Mancha.
Menerault, P. (1998). Processus de territorialisation des réseaux: analyse de la grande vitesse ferroviaire á l'échelle régionale. *Networks and Communication Studies NETCOM, 12*(1, 2 & 3), 161–184.
Offner, J. M. (1993). Les "effets structurants" du transport: mythe politique, mystification scientifique. *L'Espace Geographique*, (3), 233–242.
Peter, H., & Pain, K. (2006). *The polycentric metropolis-learning from mega-city regions in Europe*.
Plassard, F. (1990). TGV et aménagement du territoire. In Association Villes et TGV. (Ed.), *Congress Villes et TGV at Le Creusot*, Paris: TEN.
Priemus, H., Nijkamp, P., & Banister, D. (2001). Mobility and spatial dynamics: an uneasy relationship. *Journal of Transport Geography, 9*(3), 167–171.
Pumain, D. (2004). *Scaling laws and urban systems*. Working Paper, No. 04-02-002. Santa Fe, New Mexico, USA: Santa Fe Institute.
Pumain, D., Saint-Julien, T., & Sanders, L. (1986). Urban dynamics of some French cities. *European Journal of Operational Research, 25*, 3–10.
Rabin, G. (2004). Les impacts économiques pour les villes et régions desservies. In *Proceedings of CESA (Conseil Economique et Social Alsace)*, TGV: 20 ans d'expérience: Quels enseignements pour l'Alsace.
Ribalaygua, C., Sánchez, J. J., Coronado, J. M., Garmendia, M., & Ureña, J. M. (2006). *Línea de alta velocidad Madrid-Barcelona: primeros estudios y reflexiones sobre las ciudades intermedias*. VII Congreso de Ingeniería del Transporte, Edited Congress Acts.
Rietveld, P. (1989). Infrastructure and regional development. *The Annals of Regional Science, 23*, 255–274.
Rietveld, P., & Vickerman, R. (2003). Transport in regional science: the "death of distance" is premature. *Papers in Regional Science, 83*(1), 229–248.
Shiftan, Y., Ben-Akiva, M., De Jong, G., & Hakkert, S. (2002). Evaluation of externalities in transport projects. *European Journal of Transport and Infrastructure Research (EJTIR), 2*(3/4), 285–304.
Spiekermann, K., & Wegener, M. (1994). *The shrinking continent: New time-space maps of Europe*.
The Business Line, India. (May 4, 2005). *274 Central sector projects suffer cost, time overruns*.
Troin, J. F. (1995). *Rail et aménagement du territoire. Des héritages aux nouveaux défis*. Paris: Edisud. United Nations Development Programme (2001), Human development report, New York, U.S.A.
Ureña, J. M., Coronado, J. M., Escobedo, F., Ribalaygua, C., & Garmendia, M. (2006). Situaciones y retos territoriales de la Alta Velocidad Ferroviaria en España. *Ciudad y Territorio-Estudios Territoriales, XXXVIII*(148), 397–424.
Ureña, J. M., Menerault, P., & Garmendia, M. (2009). The high-speed rail challenge for big intermediate cities. A national, regional and local perspective. *Cities, 26*, 266–279.
Van Den Berg, L., & Pol, P. (1997). *The European high-speed train-network and urban development*. European Regional Science Association, 37th European Congress, Rome, 26–29 August.
Vickerman, R. (1997). High-speed rail in Europe: experience and issues for future development. *The Annals of Regional Science, 31*, 21–38.
Vickerman, R. (2007). *Recent evolution of research into the wider economic benefits of transport infrastructure investments*. OECD, International Transport Forum Joint Transport Research Center. Discussion Paper, No. 2007-9, December.
Willigers, J., Floor, H., & Van Wee, B. (2007). Accessibility indicators for location choices of offices: an application to the intraregional distributive effects of high-speed rail in the Netherlands. *Environment and Planning A, 39*, 2086–2098.