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Benchmarking Socio-Economic Impacts of High-Speed Rail Networks Using K-Nearest Neighbour and Pearson's Correlation Coefficient Techniques through Computational Model-Based Analysis

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Featured Application: This research is the world's first to assess the widespread benefits of HSR services to entire societies, including the young generation and adults. Also, the big data analytic techniques have been established through models in Python incorporating KNN and PCC techniques.

Abstract: Not only have high-speed rail (HSR) services stimulated the economy of many countries, but they have also significantly uplifted quality of lives (QoL) of countless people. For many decades, the aspiration for HSR network development has dramatically risen, and HSR networks have inevitably become an icon of civilisation. However, only a few successful HSR networks globally can truly generate socio-economic impacts on their societies. This research aims to understand the impact of HSR networks on social and economic impacts and to provide recommendations for success. This study is the world's first to examine the benefits of HSR across all community demographic groups, including young and elderly people. The findings will illustrate the QoL, economic, and educational elements' advantages in explicit terms. It has established two interconnected models via Python to codify a novel customised model for socio-economic evaluation. 'Pearson correlation coefficient' and 'K-Nearest Neighbour' techniques are applied to bolster the reliability of the research findings. The outcomes have been reviewed by 30 international HSR specialists. The benchmarking exhibits that socio-economic impacts apparently occur across vast areas. The insight stemming from this benchmarking also offers policy implications and empirical data for long-term HSR improvement, assisting the government in developing new methods for sustainable communities.

Keywords: socio-economic; high-speed rail network; population dynamics; social impacts; big data

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1. Introduction

The development of HSR services has been ultimately seen as a catapult for boosting the potential of cities and for unlocking societal benefits. The development of HSR services has gained significant momentum in 18 other countries due to the successful paradigm of the Shinkansen network in Japan. The Shinkansen service has played an essential role in improving social, educational, economic, and human lives. Additionally, Shinkansen services are reported to have provided a variety of benefits, such as an increase in convenience, reduction in travel time, opportunities for development of new areas, and regional expansion [1–3].

HSR services are perceived to be a new and smart alternative to the public commuting system because they have the ability to encourage economic growth. The service stimulates urban-suburban linkages. Passenger demand is soaring across the country because of the

wide and seamless connections provided by HSR networks. For instance, not only does the Chinese HSR network enable domestic travels within the country, but it also connects China with its borders, expanding economic potentials (i.e., Belt and Road Initiative). The HSR network is expected to enhance China's GDP up to 3% [4,5]. Likewise, a massive extension of HSR systems in European counties can also be observed. The EU has spent roughly 24 billion euros in HSR system since 2000, resulting in a rise in network lengths from 643 to 9226 km between 1985 and 2020 [6,7]. With this growth in the HSR networks, the number of passengers using the service has been stimulated from 15 to 124 billion passenger kilometres during 1990 to 2016 [8,9]. HSR systems offer convenient travels to passengers across borders, and stimulate EU countries' economies, in terms of productivity boost, growth of employment, and enlargement of local markets.

While the socio-economic benefits are evident in the current society framework, particularly from the adults' perspective, these benefits do not adequately represent the collective goals of the entire population. Therefore, this study addresses a knowledge gap by examining the socio-economic repercussions for all stakeholders, including non-adult group, in terms of living quality, educational possibilities, and socio-economic benefits. This research emphasises advantages and disadvantages of HSR service. The World Bank's social factor data sets were conducted from the beginning of HSR operations. The purpose of this research is to determine the socio-economic implications of a range of important HSR systems through the use of source data sets. The study's new findings are important for policymakers as they examine present HSR networks and establish an effective plan for HSR networks.

In the fact, only a few high-speed rail networks were carried out effectively. Most of networks have failed to earn a profit as a result of poor traffic induced by perceived disadvantages into society. In this study, CR (Chinese Railway, China), SNCF (Société nationale des chemins de fer français, France), JR Central (Japan Railway Central, Japan), Korail (Korea Railroad Corporation, Korea) and Renfe (Renfe-Operadora, Spain) networks are taken as case studies. To measure the socio-economic benefits of HSR networks, this study developed novel Python models with data imputation and PCC techniques. Regarding the data imputation technique, the study provides four methods composed of mean value, nuclear norm, KNN and median methods. Only the fittest model with the data sets is chosen for the imputation stage.

Socio-economic factors then categorise the results into three categories: QoL, educational and economic. The novel contribution of this study has a broad range of applications in benchmarking socio-economic benefits from various HSR networks. Moreover, this research has embarked on a comprehensive survey to obtain expert opinions to further enhance the data analyses from 30 global HSR experts, who work in both academics and industry. The global expert review is unprecedented. It highlights the importance of authenticating the insights and enabling the conversion of adaptive policy into actionable suggestions for the sustainability of HSR networks.

2. Literature Review

HSR networks have apparently brought on both direct and indirect benefits to society. Socio-economic conditions, including population growth and regional economic growth, are recognised as indirect benefits derived from HSR services. Previous research has carefully considered the potential effects of HSR; for example, tourists prioritising transportation systems as a crucial factor [10]. Moreover, traffic demand was increased by 10% in the short term if travel time was reduced by 20% [11]. This could confirm that socio-economic development has theoretically occurred due to HSR services. There have been numerous studies that have investigated the effect of HSR networks in a wide range of areas, as outlined below.

2.1. Reduction in Travel Time

The impact of shortened travel time that has occurred from rapid technical improvements has been carefully researched. The benefits of HSR services exceed the drawbacks of competing modes of transportation. HSR considerably lowers travel times across cities when compared to conventional rail services. The fundamental advantage of HSR is the reduction in travel time, since large time savings encourage travellers to use HSR services [6,12].

Since HSR services have become a travel choice, they have gained market share from competing for transportation modes, especially airlines. This is because it can offer high-frequency train services, providing shorter travel times, connecting major cities, and providing convenient services. Moreover, shorter travel times are the biggest factor in fulfilling the demands of consumers [12]. Therefore, the efficient range of HSR services has been covered in many publications; however, the exact distance has not been revealed as it depends on uncontrolled factors. The most suitable and effective distance is between 483 and 692 km [13,14], whereas some scholars has suggested the range 500–700 km as appropriate for services [15,16].

Travel times are shortened owing to HSR's operating speeds and station accessibility. Nowadays, most HSR services have been compared to airline services in the worthiness of travel time and cost. For example, the California HSR intends to link both of the state's economic hubs (Los Angeles and San Francisco). According to the US High-Speed Rail Association's findings, the minimum journey time is 190 min for HSR services, while airplane and car trips take 320 and 440 min, respectively [17,18]. Another example, European HSR services appeared to be more competitive with medium-haul airlines because they are related to travel duration [19,20]. For example, Eurostar had gained a major portion of the market share in the London-Paris service [21,22]. To summarise, HSR expedites check-in, immigration, and queuing up. Additionally, due to convenient station access, HSR services shorten journey times between cities and airports.

2.2. Dynamic of the Population

The regional interconnection of HSR service networks is their most important attribute. One of the major factors determining the ease of accessibility is public transportation, along with spatial, temporal, and individual variables [23]. It helps increase the level of community integration and gives advantages to people in surrounding communities. Dynamic of population is connected to the accessibility of urban development, relocation and other major elements of human life such as accommodation and work [23,24]. When Japan launched its Tokkaido Shinkansen service, it was found that there was a population growth of 22% in cities with train stations. This was an increase of 16% compared to the cities without HSR stops [24,25]. One half of the areas with HSR stations showed population increase higher than the national average. In Tohoku Shinkansen, cities near HSR stations had a 32% population rise, while areas without HSR services saw no significant population growth [26].

In Spain, residents prefer to stay in Ciudad Real, a big city. The impact of Spanish HSR illustrates by solid demand for housing near HSR stations. The reason is that the service offers travel options between the city and other major cities [27–30]. Moreover, Swedish HSR has shown that the network has attracted more citizens to live in the outlying town of Eskilstuna with a HSR station providing good links to Stockholm [31].

Studies have shown the benefits of greater accessibility via the time-space convergence effect, which may be seen as a consequence of regional expansion [25]. HSR services also create regional spatial inequalities since the inhabitants' areas with HSR stations offer better QoL due to longer-term connections [6,32,33].

As for the labour force and employment, both of these are major factors relating to population dynamics. Many researchers have pointed out that HSR services directly impact an area's employment rate and economy. Additionally, the size of the labour force has been found to have increased after the implementation of HSR services as they offer

accessibility between workplaces and residential areas. In Japan, some employment sectors, such as food retailing and accommodation, showed significant benefit from Shinkansen services [34,35].

In Europe, most HSR stations are in cities, connected to city-wide transit systems. For this reason, European networks are more accessible and beneficial to employment [36]. Similarly, HSR services have been related to job opportunities in cities. For example, more than 22,000 positions will be hired along with the High-Speed 2 (HS2) line by 2026 [37]. Moreover, 100,000 more jobs were expected with the Atlantic HSR in Spain [38]. Scholars have researched the French LGV on growth, with some measurements of the impact being in-depth, looking at employment density in suburban areas [39]. The findings clearly indicate that the number of job possibilities has grown across towns with HSR; on the other hand, non-HSR cities are showing growth in the job market. Therefore, expanding job opportunities can be linked to other factors.

HSR services bring positive effects for local businesses and the economy. The opening of HSR lines provokes investment in various businesses such as real estate, tourism and community facilities. HSR services contribute more to the limited supply than air services [40]. This is not only through a reduction in travel costs, but these services still reduce travel time. This becomes a crucial tool for increasing the potential of local markets, especially for the services sector, such as marketing. In addition, another research states that reasonable travel costs can enhance local benefits. This is because urban productivity and economic activities can be spread to neighbouring areas, where people can be reached by HSR networks [41].

2.3. The Value of Property and Land

Increased access to other destinations increases property and land values. Property values around stations have risen in recent years, as evidenced. Property near 0.25 miles of a train station is 12.2% more expensive than residential property. Prices also vary by 4.2% between zones near railway stations and others [42]. It is also important to note the effect of train stations on property prices [43].

Furthermore, many researchers have shown that HSR stations have a statistically substantial beneficial impact on property and land values in the surrounding area. One example of this is the increase in real estate sales and rates in Le Mans, France, where transactions in land and buildings rose twice within three years after the HSR opened, and the price of property went up twice in the same time period [44]. On the other hand, there was no obvious effect on land and housing prices in Taiwan when HSR accessibility was increased [45].

Monitoring the increase of land values prior to and after the opening of HSR stations is crucial to determining the most significant influence. Many scholars have studied the impact of HSR on property prices. The findings of eight HSR in the EU countries emphasised the importance of regional economies [46]. Additionally, an essential element to property cost is transportation accessibility to public services. A comparison of properties in 10 countries found that location was the primary determinant in property value, with railway stations being the most significant deciding factor [47]. Nevertheless, the level of social effect of rail services differs in each city owing to a varied number of interconnected conditions.

Many researchers had discovered certain effects of HSRs on social benefits, as shown in Table 1. Most of them rather focused on one individual socio-economic pillar, which favours an emphasis on adults. This interesting fact points to a huge knowledge gap in terms of identifying the socio-economic of an entire society, which should be concerned with all population groups. Additionally, an area of study has been essentially specific within a single city, region or country. Therefore, there is still a gap in the published analysis regarding benchmarking among HSR networks, resulting in future development failure.

Table 1. An overview of prior studies' research goals regarding socio-economic factors and knowledge gap.

Author	Socio-Economic Factors				Research Focus or Knowledge Gap
	Reduction in Travel Time	Dynamic of Population	Employment and Economic	The Value of Property and Land	
Yin et al. [12]	✓				Comparing only HSR and air in the four European countries
Román and Martín [48]	✓				The study focused on passengers' expectations of integrating HSR and air modes. The outcomes addressed in time-saving benefit.
Högdahl et al. [49]	✓				The research aims to minimise travel time and increase accessibility to railway services for Swedish railways.
Ronnie [50]	✓				The research focused on the cost-benefit of Swedish HSR
Albalate et al. [14]	✓				Comparing only HSR and air in the four European countries
Behrens and Pels [22]	✓				Comparing only HSR and air between London and Paris
Verma et al. [51]		✓			The research focused on the urbanisation of HSR in India.
Kojima et al. [15]		✓			The research represented the impact of the new Shinkansen line compared with the benefit of shortening travel time.
Obermauer and Black [26]		✓			The research revealed indirect impacts of the Shinkansen.
Jin et al. [52]		✓			The research revealed regional accessibility of Chinese HSR by using GIS. The research also compares the effects before and after launching the service.
Deng et al. [53]		✓			The research examined the urban population impact from the Chinese HSR network.
Shamionov R. M. [54]			✓		The study revealed the correlation between space and time, effects of selected European HSR networks.
Watson et al. [55]			✓		The study revealed social sustainability after coming on the HSR. The research mentioned the job, welfare, and social impact. However, the study on the young and old generation haven't been reviewed.
Yang et al. [56]			✓		The study placed a research focus on urban decentralisation in China, and the impact of the HSR service.
Cervero and Murakami [18]			✓		The research predicted the economic impacts, especially the job markets, of California HSR.

Table 1. *Cont.*

Author	Socio-Economic Factors				Research Focus or Knowledge Gap
	Reduction in Travel Time	Dynamic of Population	Employment and Economic	The Value of Property and Land	
Radopoulou et al. [57]			✓		The research examined economic geography and disparities for providing appropriate demand for the passenger.
Eyles [37]			✓		The research focused only on the employment factors of the HS2 project.
Fernandez-Macho et.al [38]			✓		The research analysed only the economic and spatial development impact of HSR
Huang et al. [58]			✓		The study found the correlation between the growth of HSR and economic impacts in China.
Monzon et al. [6]			✓		This study placed the focus on Spain's HSR during 1990–2015. However, the practice can't be adopted by other networks.
Rungskunroch et al. [59]			✓		The study focused on socio-economic impact in Japan.
Banister and Givoni [36]			✓		The research focused on the investment in the transportation network to stimulate the economy. However, other social factors have been excluded.
Blanquart and Koning [40]			✓		The research provided good practices from a socio-economic perspective, especially in the local economy. However, the study has not offered any mathematical model, which is hard to apply to other networks.
Button et al. [47]			✓		The research examined economic benefits from the HSR in the USA. It aims at providing recommendations to enhance the country's social welfare and other environmental benefits.
Chen [60]			✓		The research focused only on the economic impacts in China.
D'Alfonso et al. [61]			✓		The research compared between air and HSR modes in terms of environmental benefit and social-welfare.
Diao [62]			✓	✓	The research focused on the impact of Chinese economic geology from HSR
Gargiulo and De Ciutiis [63]				✓	The research provided insight into the property value of the 'Roma—Napoli' high speed line. It is difficult to apply to other networks.

Table 1. *Cont.*

Author	Socio-Economic Factors				Research Focus or Knowledge Gap
	Reduction in Travel Time	Dynamic of Population	Employment and Economic	The Value of Property and Land	
Rungskunroch et al. [64]				✓	The research pointed out the benefit of the land price after the coming of HSR.
Sands [65]				✓	The research studied the effects of the California HSR station.
Andersson et al. [45]				✓	Only property and land price factors have been concerned in this study.

To fill the gaps, this study assesses the effects of HSR networks while disclosing their implications in relation to population dynamics, education benefits, career prospects and other issues. Additionally, the benchmarking of five noteworthy and success HSR networks along with their social impacts is revealed.

An assortment of five networks involves multiple criteria. First, the network must be consistent and dependable, measured by a minimum of ten years of operation. The chosen networks are systematically combined terms of their geographical, technological and other relevant conditions, in order to avoid bias. Differentiation on the QoL, education and economy leads to future policy implications for the upcoming networks.

2.4. The Socio-Economic Effect of the HSR Network

The benefit of the HSR to society has been highlighted in limited areas, as mentioned in Sections 2.1–2.3. The advantage of travel time reduction, population dynamics and land price is generally addressed as long-term development of HSR projects. However, the capability of HSR service toward society can be turned out and grouped in terms of life quality, education and the economy as follows.

2.4.1. Life Quality

The increase in population and the age proportions of older and younger generations is important to quality of life (QoL). One variable that influences descriptions of population dynamics is the rise in the population. The UN research found that variations in population numbers, generation and population dispersion form population dynamics [66].

On the other hand, the relationship between HSR and life quality is measurable by how it influences the generational age gap. With regards to the seamless connection of HSR networks, many publications emphasise how HSR services enhance access to vital places such as schools, medical hubs and shopping areas [67,68]. This enhances the QoL for people who live in close proximity to train stations and catchment regions. Passenger mobility is defined differently among the age group. For example, the elderly can journey alone, whereas children are often carried by their families. Consequently, it is reasonable to anticipate that the HSR system will have a larger positive effect on elderly populations than it would on young group.

2.4.2. Education

Acquiring an appropriate education has been a vital component of society's development. This study analyses educational opportunities for the young generation at three distinct levels, including elementary, secondary and postsecondary. There is a clear relationship between these factors and the impact of HSR services on the younger generation. In reality, children in low-income nations are very restricted in educational options, and their journeys to and from school for as long as six hours a day because their homes are too far away from the school [69]. Moreover, in many industrialised countries, students

in rural areas need an educational environment equal to those who live in major cities. Therefore, the new HSR services have potentially brought equivalence to people who had difficulties accessing a proper education system. Regarding existing research, it remains unclear to what degree HSR services are attributed as having an education benefit for the young generation. However, in this research, data sets for progression to secondary school and primary completion rates have also been collected. These factors are used to evaluate the advancement of enrolled students and to reflect their capabilities.

2.4.3. Economy

Expansion of the national economy and stimulation of domestic markets are the objectives of those countries when they establish HSR networks. For example, Japan's labour market, commercial sector, and economy have been greatly assisted by introducing the Shinkansen system, which has helped set a precedent for other nations. Despite the fact that HSR networks' success may be attributed to a variety of reasons, many networks are projected to have a beneficial effect on society in the future.

With respect to unemployment and employment numbers, these factors are reflected in the economy, both locally and nationally. As mentioned in a considerable number of studies, the coming of the HSR project could enlarge business areas and increase job opportunities. At the same time, tourism and local businesses also benefit directly from growth in passenger demand. Lastly, women's job opportunities are believed to have improved with the coming of HSR. This research has analysed the percentage of female legislators in national legislatures as a factor that not only reflects the position of women, but also measures gender equality.

3. Methodology

Regarding to assessing the social impacts of HSR services, the research is based on the collection of social factor data sets distributed by the World Bank, company reports, and publications [70–75]. There are 12 social factors that have been focused on in this study. A data pre-processing stage was then put in place to validate the collected information, as shown in Figure 1. According to the evaluation of the long-term data, there are some missing values in the collected social factor information. Therefore, the KNN model has been created via Python to calculate the missing data. Lastly, the PCC has been conducted to measure the impact of social factors and of HSR network growth.

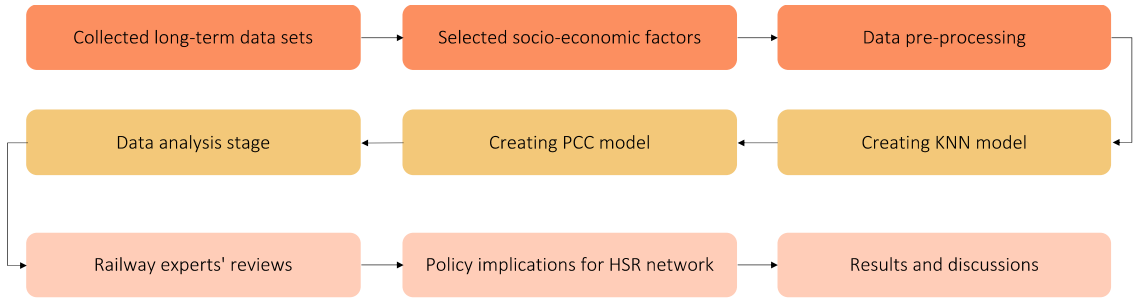

Figure 1. An overview of research methodology.

3.1. Data Collection and Pre-Processing

Accordingly, the social impact depends on various factors, such as the resident, the economy, urban transportation, business performance [76,77]. To evaluate how each HSR network has impacted and involved society, this study provides a detailed analysis of the growth of HSR since their operation until 2019 compared with 12 social factors, which were conducted from official and reliable sources such as the World Bank, HSR's financial reports, sustainability reports and publications [70–75]. Then, the research uses PCC as the main methodology for finding correlations between those factors that lead to future improvements.

These variables have been classified into three categories: quality of life (PD), education (ED), and employment (EC). Those variables represent social impacts from the growth of HSR service. The details of variables are shown as follows:

PD group: The variables in this group reflect life quality of all ages after the coming of HSR services.

- Population growth (PD1) [78]—The variable represents a country's resilience in the face of adversity. Significant population growth will deplete agricultural land and intensify food demands, social care and infrastructure.
- Age dependency ratio (young generation) (PD2) [79]—The variable shows the ratio of under 15 years old dependents to the working-age group (15–64 years old).
- Age dependency ratio (elderly generation) (PD3) [80]—The variable shows the ratio of over 64 years old dependents to the working-age group (15–64 years old).

ED group: The variables in this group reflect educational benefits after the coming of HSR services.

- School enrolment in three levels (primary (ED1), secondary (ED2), tertiary (ED3)) [81–83]—The variables are the proportion of mandatory school age students enrolled to the total amount of compulsory school age equivalents. Education is a factor in the UN's and UNESCO's development plans.
- Secondary school advancement (ED4) [84]—The variable represents the quantity of new students accepted in a given year as a percentage of the total student population.
- Completion rate of primary level (ED5) [85]—The variable represents the overall quantity of new students attending primary school in the final grade multiplied by the number of students entering at the final year enrolment age.

EC group: The variables in this group reflect economic performance after the coming of HSR services.

- Labour force (EC1) [86]—The variable represents the total number of people aged 15 and older, involved in production and service sectors.
- Employment rate (EC2) [87]—The variable represents the fraction of the employed population compared with the total population.
- Unemployment rate (EC3) [88]—The variable represents the fraction of the unemployed population compared with the total population.
- Women's representation in national parliaments (EC4) [89]—The variable represents the percentage of women elected to parliament, related to employment rate and gender disparities.

3.2. Data Imputation

The data imputation technique has been included to fill up the missing information, which is approximately 5% of the whole datasets. There were various imputation techniques applied in this study, including KNN, nuclear norm minimisation (NNM), mean value, and median value, as shown in Figure 2. The results indicate that the KNN is the most suitable method, showing the lowest error.

3.2.1. An Application of K-Nearest Neighbour Technique

Regarding the machine learning theory, the KNN technique may be thought of as a kind of supervised machine learning strategy that is frequently used to substitute values in data sets that have been missing or not been gathered. The KNN concept is sensible: it simply substitutes the most exact or closest values for missing data. The k-value depends on the amount of complete data present in the data collection. For instance, when k is selected as 4 (k = 4) this means that four nearest data points will be used to calculate, via selected functions, a new value to substitute the uncollected value. In this study, the k value is set at 5 (k = 5).

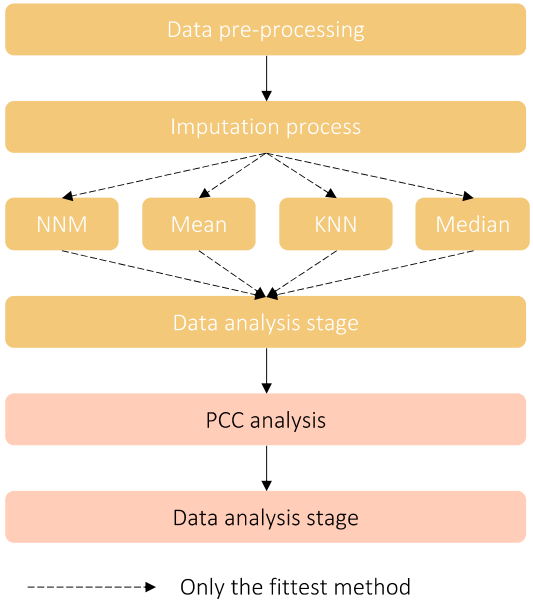

Figure 2. The overall flowchart of the data imputation stage allows four different options (KNN, NNM, Mean, Median) to calculate the most-fittest model.

In contrast, a poor selection of the k-value may result in an inaccurate evaluation of the new value. The choice of k-value must be appropriate, since using one that is too small may result in missing the trend, while using one that is too big can create issues with other variables [90–93]. Some researchers mentioned that the best match for the k-value is found by comparing multiple k-values to the data to minimise a specific inaccuracy [94]. This research applies the standard Euclidian distance form, as it can be seen in Equation (1).

$$d(a,b) = \sqrt{(a_1 - b_1)^2 + (a_2 - b_2)^2 + \cdots + (a_n - b_n)^2} \quad (1)$$

where: d = Euclidean distance among the point a and b, $a = \{a_1, a_2, \ldots, a_n\}$ and $b = \{b_1, b_2, \ldots, b_n\}$.

3.2.2. An application of Pearson's Correlation Coefficient (PCC) Analysis

The PCC plays a key role in statistical research. This method assesses a relationship between two variables or data sets [95,96]. An analysis shows a value in a range −1 to 1. Various aspects of PCC data analysis relate to this area of research. As shown in Table 2, the interpretation of the PCC differs; for example, the range for weak relationships is less than 0.3 in Psychology, 0.2 in Politics and 0.5 in Medicine. Regarding this research, values in the range ±0.1–±0.3 refer to a weak relation, ±0.3–±0.5 refer to a moderate relation and ±0.5–±1.0 refer to a strong relation [96]. A number over zero implies both variables are positively correlated, while a value below zero indicates that both factors are negatively correlated.

Table 2. The interpretation of PCC's value in engineering, medicine, politics and psychology [97].

Interpretation of Relationship	Areas of Study			
	Engineering [97]	**Medicine [97]**	**Politics [97]**	**Psychology [97]**
Perfect	−1 (negative) or 1 (positive)			
Strong	±0.5–±1.0	±0.5–±1.0	±0.5–±1.0	±0.5–±1.0
Moderate	±0.3–±0.5	±0.3–±0.5	±0.3–±0.5	±0.3–±0.5
Weak	±0.1–±0.3	±0.1–±0.3	±0.1–±0.3	±0.1–±0.3
None	0			

This study investigates how societal conditions are connected to HSR expansion by utilising the PCC analysis, as illustrated in Equation (2).

$$P = \frac{\sum(X_i - x)(Y_i - y)}{\sqrt{\sum(X_i - x)^2 \sum(Y_i - y)^2}} \quad (2)$$

where: P = correlation coefficient, X_i = social component values i, x = the average of the social variables' values i; Y_i = the overall distance of the HSR network in year i; y = the average value of the HSR network's length.

With respect to the broad benefits of PCC, many studies in railway research have adopted this method as the main methodology. Some authors use PCC to improve the efficiency of railway operation. It has been involved in improvements in safety performance in the long-term. Some scholar applied PCC to verify safety conditions at railway crossings in the event of extreme weather. The research revealed that some indicators should be adjusted to assess the conditions of railway crossings such as fatigue spots, an irregular contact ratio [98].

The PCC has also been broadly applied for the enhancement of technical services of railway. Sönmez and Ozturk focused on traffic loads and track parameters with the aim of evaluating vertical and lateral rail wear [99]. Traffic loads are unpredictable information based on uncertain passenger numbers and volumes of materials. Another study focuses on correlations to track geometry, especially the correlation between track stiffness and variable settlement. By using PCC, precise measurement of vertical track stiffness was obtained, providing better upkeep and environmental sustainability [100].

Additionally, PCC has been used in urban planning for categorisation. Areas surrounding train stations have seen better management and long-term improvements due to these findings. Some scholar used PCC to analyse 1700 Swiss railway stations using contextual factors such as density and purpose for use of rail services [101]. PCC clearly offers classification in the context of the system structure, with the outcome providing strategic planning for railway stations to support a fluctuating level of passenger volume. Using PCC, Huang et al., researched how Chinese railway network dynamics had a major effect on a variety of other networks [102]. The outcomes indicated effective policies for future investigation.

To validate the accuracy of the models in this study models, they are compared with the PCC analysis of French HSR investment on the economics of urban agglomerations. Other research has used the same methodology to measure the correlation between HSR networks and population in the period 1981–2009, giving a correlation outcome of 0.981 [103]. Additionally, the validation of the research's PCC models shows in Appendix A.

4. Results and Discussion

Using PCC, the network has revealed the outcomes associated with these 12 factors, as illustrated in Table 3. PCC-outcomes are in the band of −1 to 1, showing the level of correlation with HSR network growth. Moreover, the whole correlation analysis for all countries is shown in Figures 3–7.

Additionally, in this research the factors are arranged in three pillars, with the average results illustrated in Table 4.

4.1. The Impact of HSR Network on Socio-Economic Growth

This section describes the results of the correlation analysis among the five networks that are clearly reflected in socio-economic growth, as shown in Figure 8. HSR services show a strong relationship with social impacts.

4.1.1. SNCF Network (France)

The SNCF network has the most significant influence, with an average impact of 0.51. Between Paris and Lyon, the first French HSR service (TGV) began in 1981. Subsequently,

the network was stretched throughout the country and connected to networks in other nations. The social impacts of SNCF network found that the QoL had the most significant impact. This argument is borne up by an assessment of France's low-cost, high-speed train system, namely 'Ouigo', which has grown into a more desirable service than low-cost travel. Ouigo's services are primarily geared toward leisure travellers looking to prepare ahead.

Moreover, TGV meets the enormous demand of travellers in the largest cities of France [86]. The services have been hailed for their superiority in journey time reduction versus aeroplane services. By utilising HSR services, passengers may save a half-hour on the security process at the airport. Therefore, it implies that the TGV service can save at least an hour on round trips [104,105]. Furthermore, HSR provides affordable services using many marketing strategies (i.e., early booking, return prices and promotional tickets). The research's outcomes indicate that the TGV has improved Frace's QoL, as demonstrated by the PCC score of 0.9.

Table 3. The summarisation of PCC results among five HSR networks.

Socio-Economic Factors (Abbreviation)	Pillar	PCC's Results				
		CR	SNCF	JR Central	Renfe	Korail
Population (PD1)	QoL	0.97	0.97	0.94	0.93	0.93
Age dependency ratio, (under 15) (PD2)	QoL	−0.03	0.75	−0.94	−0.88	−0.27
Age dependency ratio, (over 64) (PD3)	QoL	0.89	0.97	0.88	0.95	0.92
School enrolment, primary (ED1)	Education	−0.92	−0.77	0.24	−0.82	0.08
School enrolment, secondary (ED2)	Education	0.89	0.6	0.96	0.8	0.93
School enrolment, tertiary (ED3)	Education	0.94	0.94	0.92	−0.37	0.94
Secondary school advancement (ED4)	Education	−0.71	0.5	0.69	0.21	0.55
Completion rate of primary level (ED5)	Education	−0.68	−0.17	0.24	−0.41	−0.35
Labour force (EC1)	Employment	−0.95	0.17	−0.75	0.66	0.84
Employment rate (EC2)	Employment	−0.96	0.34	−0.78	0.62	0.38
Unemployment rate (EC3)	Employment	0.52	0.27	−0.66	−0.47	−0.25
Women's representation in national legislatures (EC4)	Employment	0.89	0.9	0.6	0.91	0.89

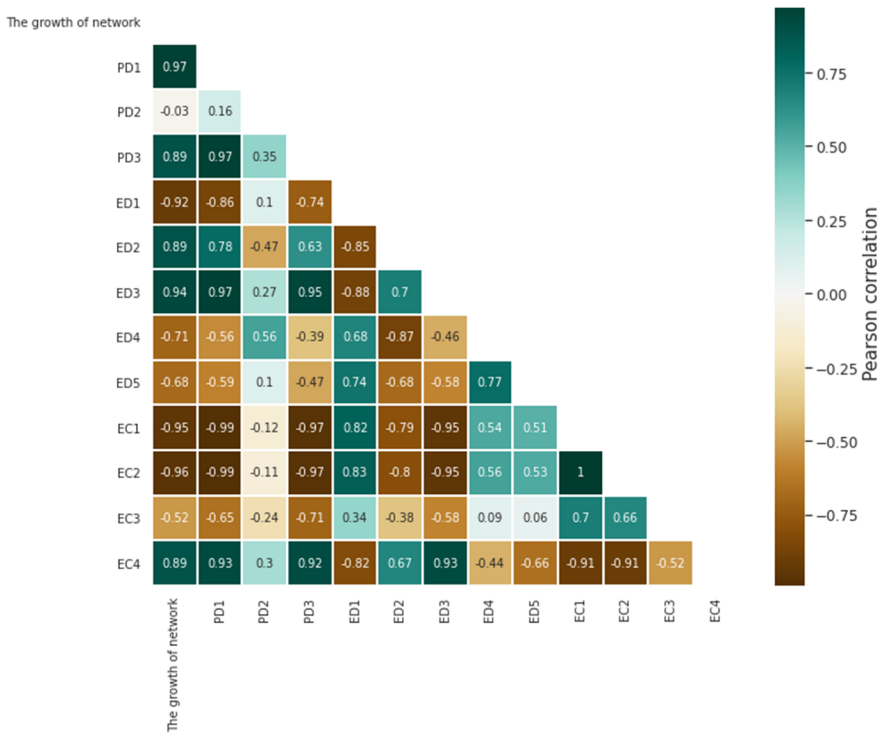

Figure 3. The PCC's outcome of CR network.

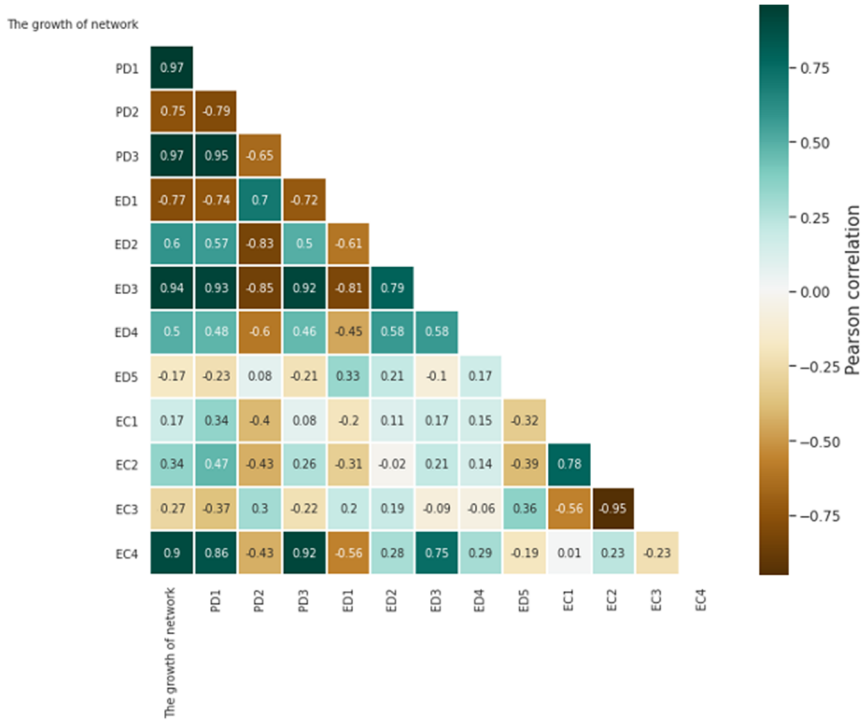

Figure 4. The PCC's outcome of the SNCF network.

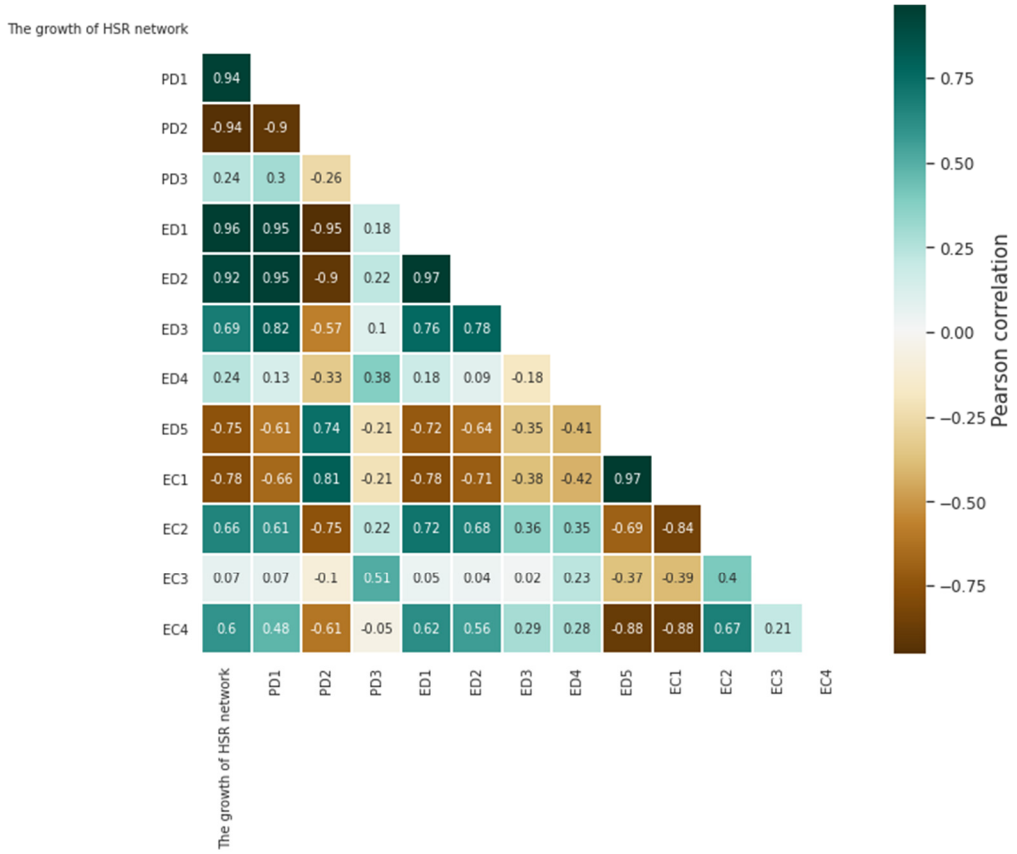

Figure 5. The PCC's outcome of the JR Central network.

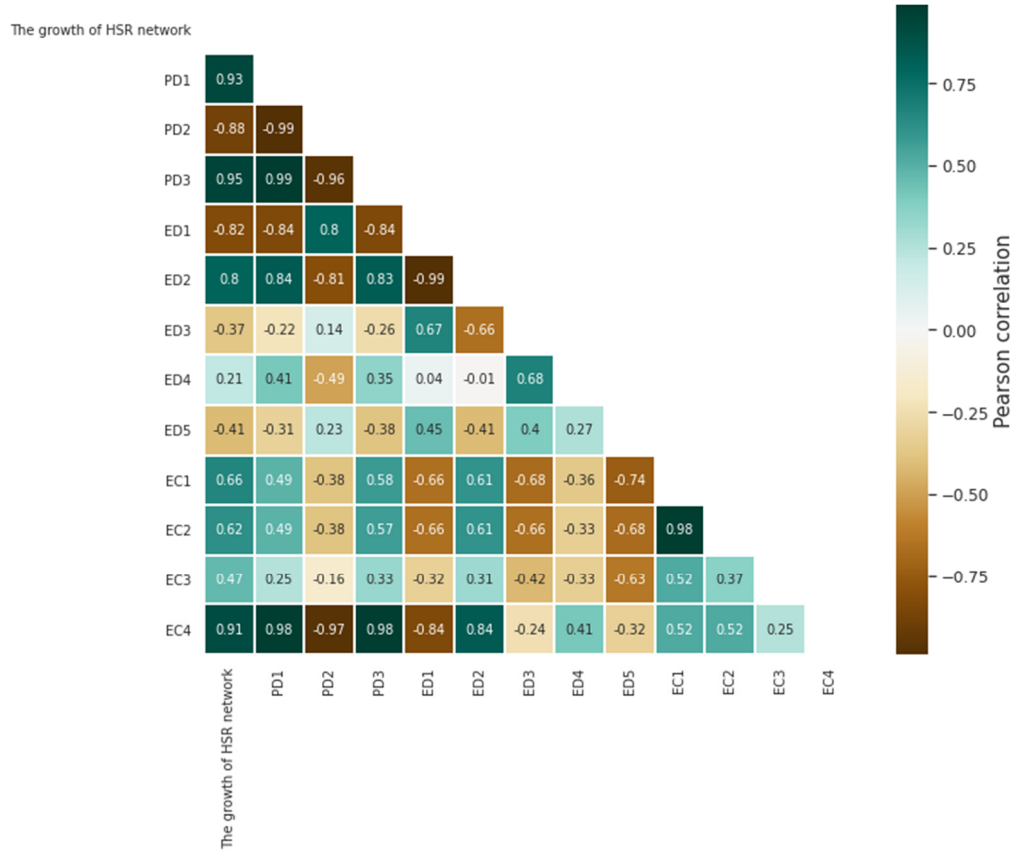

Figure 6. The PCC's outcome of the Korail network.

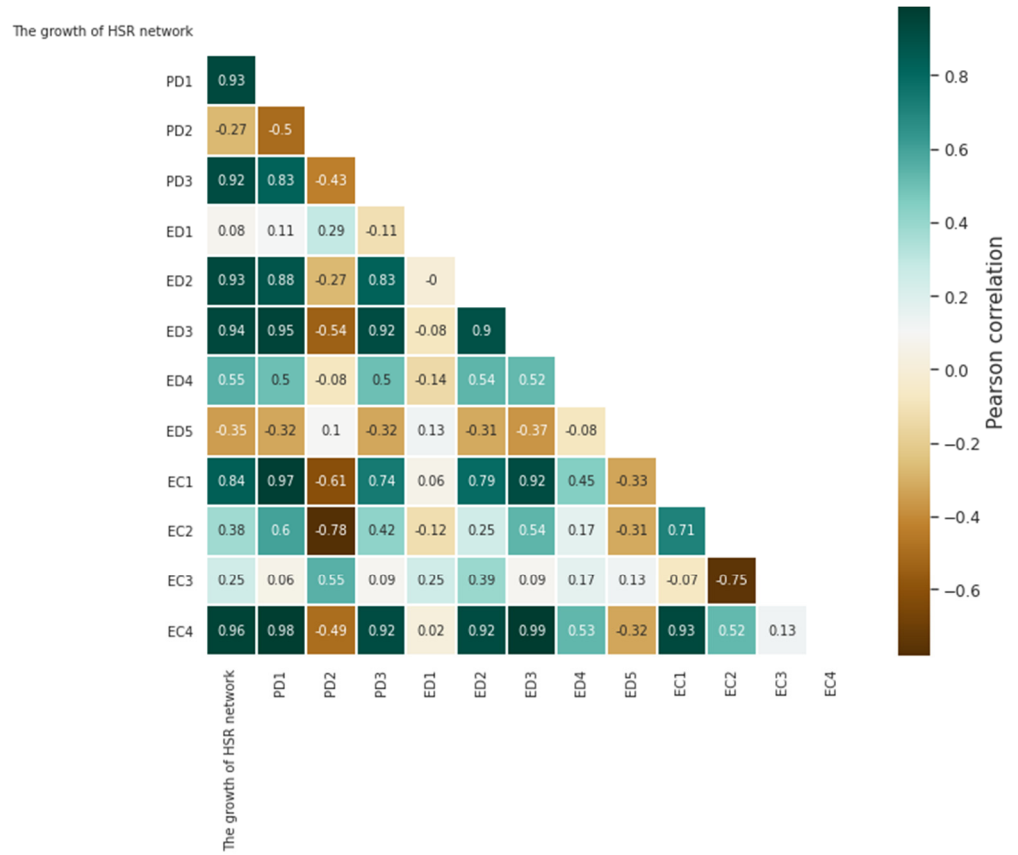

Figure 7. The PCC's outcome of the Renfe network.

Table 4. The summarisation on PCC results in QoL, education and employment of each HSR network.

HSR Network	SNCF	Renfe	CR	Korail	JR Central
QoL	0.9	0.53	0.61	0.34	0.08
Education	0.22	0.43	−0.01	−0.12	0.41
Employment	0.42	0.47	−0.13	0.43	0.14
Average	0.51	0.47	0.13	0.22	0.21

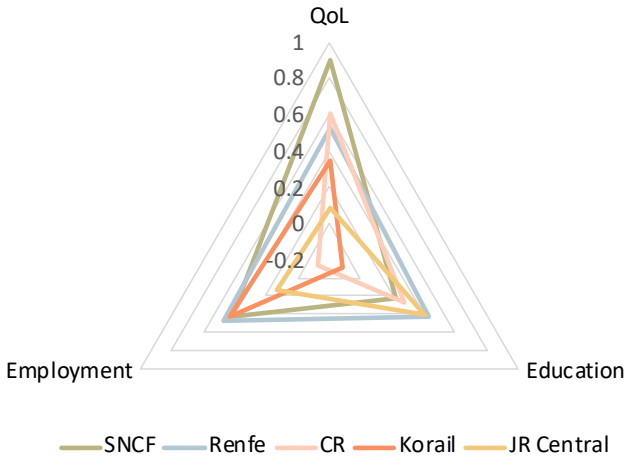

Figure 8. The summarisation of three pillars by networks.

In terms of employment, the correlation coefficient among EC1, EC2, EC3, EC4 and HSR network growth is 0.42, showing a reasonably favourable link. The growth of high-speed rail stations in France has reduced travel times, increased mobility and benefited urban economies [106]. The shortened travel time may assist businesses in more easily distributing their products and services in France [107]. Reduced travel times, improved train frequency, and reasonable rates all contributed to expand accessibility to HSR services. For example, the current train journey time between Reims and Paris has been lowered from 1.35 h to 45 min, whereas the advance fare of €10.53 remains same [108]. According to various academics, TGV facilitated the establishment of new businesses in Paris, which had become an increasingly crucial component of business, notably in the sale of services [108]. This is because, as a consequence of increased activity and productivity, TGV services have enabled companies to expand their exposure and accessibility to customers. As a result, the French network has been able to directly and indirectly enhance the country's labour market and economy.

Finally, the SNCF network's average value for the education pillar is 0.22. Indeed, no comprehensive study of the link between French schooling and the TGV service has been published. According to PCC data, secondary (ED2) and tertiary school (ED3) enrolment rates are strongly related to network expansion, although the connection is weak at the primary level (ED1). The long-term impact of HSR on France's educational system is unknown. The SNCF network has had a large positive impact on society, primarily via advances in QoL, the economy, and education.

4.1.2. Renfe Network (Spain)

In the case of the Spanish HSR network, it also has considerable social benefits, showing a PCC average of 0.47. Renfe entirely operates the Spanish HSR system, and it is well-known as AVE service. The network has received a large volume of investment on infrastructure and operations. Moreover, the Spanish government had launched a plan to enlarge the project across countries that would require a large amount of investment [109].

Concerning this point, many experts believed that the AVE network could not offer social benefits to Spanish speakers. Some scholars studied the financial and social viability of four main AVE routes. The accessibility to railway services has been improved since the

AVE services have been operated [13,28]. After analysing the spatial distribution, the result shows that the accessibility value of AVE had improved by almost 50% [6]. Additionally, the study discovered that AVE services benefited territorial cohesiveness, EU's development priorities. A seamless connection can also reduce disparities between regions. Similarly, the outcomes of this study imply that AVE services benefit large regions more than small nations. On the Renfe network, the median PCC score for QoL is 0.53. Additionally, the research reveals that while older groups (PD3) profited positively, showing a PCC score of 0.92, the network is unhelpful to young persons (PD2).

Our findings reveal that the employment pillar (EC1–EC4) has a PCC-value of 0.47, a very high correlation. According to studies, the Renfe network's mobility influences the labour supply. As found in the study of four urban cities in Spain, the AVE network was associated with temporary migration, particularly for short-term and consultancy jobs [110]. Additionally, station placement encourages labour mobility and broadens the labour market. As a result, it revealed a positive effect on the local tourism business [111].

There has been no research highlighting the educational advantages of rail networks in Spain. Additionally, the average PCC value for the education pillar is 0.43. Indeed, Spain's employment rate has been increased in recent years as a result of rising educational enrolment. Around 60% of the unemployed lack formal education or are low-skilled workers. Additionally, the bulk of them has prior experience in the building sector [112]. Renfe network offers regular service at low prices to fit employees' schedules. As a result, the Renfe network has helped the entire population of all pillars as mentioned earlier.

4.1.3. CR Network (China)

Chinese HSR services are crucial in distributing industrial resources such as workers, commodities and services in facilitating enterprises. As a result, the services can significantly increase corporate agglomeration [113,114]. CR network also suits business passengers, who require high-convenience services and need to save on journey time. Because of the service's high earning expenses, low-income parties, students and non-commercial organisations may not likely pay for HSR rates [115,116]. Since network can sustain only wealthy passengers, the PCC value on the economy (EC1–EC4) is −0.13. Likewise, the results of the PCC for Chinese education (ED1–ED5) are low with a value of −0.01. To sustainably improve the CR network, affordable fares for the middle class should be a priority. In addition, the service should apply new techniques and marketing strategies such as student discounts, advance tickets, and return rates to increase passenger volume.

The findings show that the network's growth was strongly linked with China's QoL (PD1–PD3), which shows the PCC value at 0.61. The Chinese's conventional rail was the key transportation system in China, but the CR network has offered faster services. Considering the major cities in China, most of them are located long distances apart on the east coast of the mainland. For instance, Beijing and Shanghai are China's leading commercial areas. Both cities are separated by 1200 km. To travel between them, CR services take approximately four hours, instead of 12 h by car. The network has also transformed into a competitor for airplane services. Passengers should factor in extra time for travel and terminal-related activities while travelling, as only the flight itself takes more than two and a half hours [117]. Additionally, air fares are slightly more costly than HSR tickets. Thus, not only do CR services enhance people's lives, but they also catalyse the transportation sector.

4.1.4. Korail Network (South Korea)

Some statistics reveal that South Korean passenger transportation has been affected within a radius of 200 km from the capital. Whereas, some researchers argued that the typical flow of Honam KTX is 40 km, according to a population flow study [118,119]. In the fact, the distance in a range 20–25 km from the Seoul station is the most crowded area. The main conclusion from the previous arguments is that South Korean HSR (KTX) may affect essential places like the centre and CBD, and the system can be very effective across more

than 500 km in length, but the length of KTX major routes is only 346.4 km. Nonetheless, this research's results indicate that the QoL's PCC value (PD1–PD3) shows at 0.33, and the employment value (EC1–EC4) is 0.43, which means that both factors have a reasonable relationship to the development of the HSR system.

Furthermore, KTX's improvements and geographical dispersion along the Gyeongbu line affect micro-level population and employment distribution [120]. Then, mobility levels declined; this was a short-term impact. There are very few job opportunities in the city since businesses are situated distant from the central districts. Therefore, the KTX has impacted a limited group of people and shows a low correlation with the country's economy. In terms of educational benefit (ED1-ED5), the negative correlation of −0.12 seen in the PCC value indicates the KTX system is weak. However, this research is the first study that highlights South Korea's educational benefit from KTX services.

4.1.5. JR Central Network (Japan)

With respect to the nation's economy, during its early stage, the JR Central network seems to have influenced the labour sector. Numerous scholars studied the impact of the JR Central on migratory patterns, especially on the factors in the labour force. Some researchers discovered that the rate of rise was estimated to be roughly 1.8% in areas next to HSR stations, but just 1.3% in areas lacking the stations. Moreover, the employment growth in regions with Shinkansen services increased by 34% [24]. On the other hand, in the following years, the employment rate has decreased. Nakamura and Ueda found that the participation rate for workers fell by 2.8%, compared to 3.6% in regions without HSR services [121]. In addition, the IT industry had increased by 22%. This indicates a very limited impact on the employment sector by the Shinkansen system. Businesses engaged, such as grocery retailers and the housing industry, expect a high level of station accessibility [25]. As observed in different industries and locations, the general advantage of the Shinkansen network to Japan's labour force had decreased. Likewise, in this research, a PCC result of 0.14 implies that the extension of the Shinkansen line was weakly favourable.

The outcome of the QoL's PCC is 0.08. In addition, the findings of PCC are −0.94 and −0.24 for age dependence ratios, young (PD2) and elderly (PD3). It can be implied that the JR Central network offers more QoL benefits to older groups than younger groups. However, younger groups obtain great benefits as education has a coefficient of 0.41, which is also higher than other nations. To our knowledge, no research has assessed the details of the educational benefits of the Shinkansen network. The interesting statistics of primary (ED1), secondary (ED2) and post-secondary (ED3) student attendance rates that have a PCC rating of 0.96, 0.92, and 0.69, respectively, are worth studying. The research's findings show a significant connection with the growth of the network.

5. Expert Opinion and Feedback on a Practical Railway System

While this study takes a long-term socio-economic perspective and analyses through efficient novelty models, it also includes expert reviews of the study's conclusions to assist in putting this critical input into effect. Our professional opinion is acquired in compliance with EU data protection law (GDPR).

A total of 30 global HSR experts (or six specialists from each network) have participated, including academia, industry and research expertise. They must have experience of at least 15 years and currently hold at least one position connected to the railway sector. Participants must know at least one of the listed rail networks. Each participant can also select only the networks that best reflect their experience. Before participating, they must read through the in-depth network's data analysis, in Figures 3–7. At any point during the survey, the participant may refuse to participate or leave blank any questions they do not wish to answer.

The expert responses were scored using a five-point Likert scale, with 1 indicating 'strongly disagree' and 5 indicating 'strongly agree'. The overall results for expert agreement with the data analysis for each rail network, as shown in Figure 9. The average score for

experts on the CR, SNCF, Korail, and Renfe networks ranges up to 4.8, equivalent to levels of agreement with our judgements ranging from 'agree' to 'strongly agree'. In comparison, the score from the JR central network's experts is 3.2, indicating that they neither oppose nor agree with the JR central system's interpretation. Note that one of them has claimed that the JR central network has improved Japanese factors for many decades. Nevertheless, the services have been affected by the disturbance to the Japanese society caused by multiple waves of the COVID-19 pandemic.

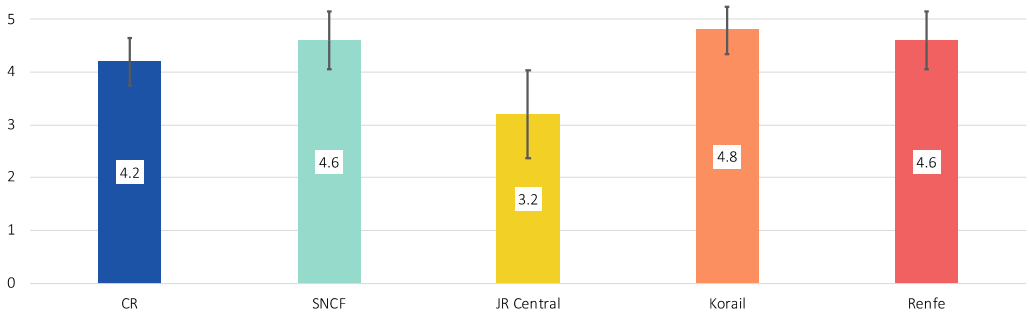

Figure 9. The degree to which railway specialists agree with the benchmarking analysis carried out by networks.

The response also contained a section on effective policy goals for sustainability, each of which was also assessed on a Likert scale from one to five points. The selected policy goals are: (i) Connecting to various modes of public transportation hubs; (ii) providing access to important cities; (iii) offering reduced or special tickets; (iv) increasing the social value of areas next to HSR stations; (v) connecting business districts and tourist attractions; (vi) offering ticket rates that are reasonable; (vii) extending the validity of early and late tickets; (viii) expanding commercial districts next to HSR stations.

It is inevitable that all eight factors support both social and economic impacts from HSR services, and are necessary for the development of a HSR system. Nevertheless, there is a differentiation in the background effects of the different networks on the proposed policy implications. Table 5 represents the overall average results of the opinion and feedback from 30 global experts. For promoting socio-economic impacts of HSR networks, 'connecting to major cities', with an average score of 4.8, is the highest priority for an application to rail services. Many experts believe that a seamless and broad connection is the most important factor in enhancing socio-economic impacts for all population groups. In addition, 'Connecting to various modes of public transportation or transportation hubs', 'Offering reduced or special tickets, and 'Connecting business districts and tourist attractions' are also necessary factors to drive HSR network.

Table 5. An overview of railway experts' feedback regarding policy implications.

Ranked	Policies Implications	Average (±Standard Deviation)
1st	Providing access to important cities	4.80 ± 0.24
2nd	Connecting to various modes of public transportation or transportation hubs	4.76 ± 0.26
3rd	Offering reduced or special tickets	4.68 ± 0.41
4th	Increasing the social value of areas next to HSR stations	4.60 ± 0.24
4th	Connecting business districts and tourist attractions	4.60 ± 0.36
6th	Offering ticket rates that are reasonable	4.52 ± 0.44
7th	Extending the validity of early and late tickets	4.48 ± 0.95
8th	Expanding commercial districts next to HSR stations	4.44 ± 0.30

Nevertheless, the priorities for policy implications should follow a network's internal conditions and background. The comparison of mean value for policy implications of each network is shown in Figure 10. In comparison with other techniques, expert feedback has advantages in precisely revealing practical methods to use with specific networks.

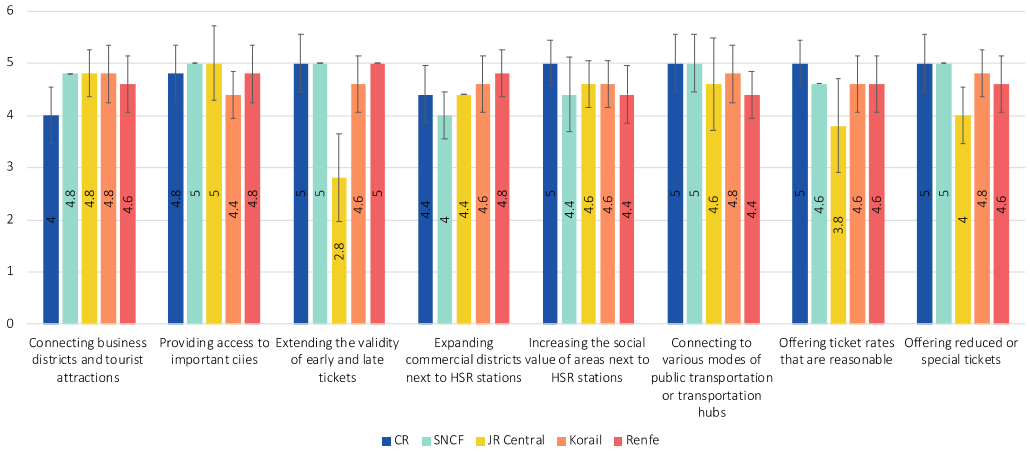

Figure 10. A summary of railway experts' responses to questions on policy implications by networks.

6. Policy Implications

Apart from the experts' feedbacks towards the PCC result of the selected HSR network, in-depth policy implications are provided in Section 5. Moreover, by following the global perspective on social and sustainability, the long-term development of HSR networks includes two kinds of policy implications: current and future networks' regulations. This study offers suggestions regarding service fees and train schedules for any existing HSR networks.

6.1. Service Fee

One of the most critical problems is that people cannot afford HSR fares. This is because some HSR networks offer high ticket prices compared to standard national salaries. For this reason, HSR networks suit only high-class travellers, while most of the population cannot afford this service. In fact, most rail authorities offer special promotion to non-adult groups.

Some railway companies offer special prices for tourists; for instance, a Japan Rail Pass (JR Pass) for unlimited trips on Shinkansen services [122,123]. Nevertheless, there are no special prices or discounts for workers or low-income groups. This study suggests offering workers specially priced HSR tickets on weekdays. This will be a direct benefit to people who regularly travel to/from their homes and workplaces. These strategies can generate long-term benefits for a country's workforce and economy.

6.2. Train Schedule

Train schedules play an important role in supporting passenger demand. Based on this study, the growth of a country's economy and labour market is not related to HSR services. Despite services to business areas and the offer of reasonable prices, workers may choose to travel by other modes of transportation. This is because train schedules are ineffective for all groups of people, especially those who live in suburban areas. By following the findings, HSR services offer a genuinely positive impact in terms of the education pillar. Moreover, the service is likely to stimulate strong student enrolment rates for all levels. This research highly recommends that HSR companies track demand for travel demand at specific times. It will benefit people who require early and late running services, especially for the young generation.

Regarding any upcoming HSR projects, recommendations are additionally suggested in relation to: route and operating distance, location of HSR stops and hubs, and information on intermodal transportation.

6.3. Route and Operating Distance

In fact, some HSR routes have been constructed with the aim of linking major regions, without considering the side-effects for nearby medium or small cities. Moreover, operating distances also have a definite impact on the success of HSR services. This study highly recommends that the construction of new HSR networks should take effective routes and distances into consideration. As reviewed, HSR has proved more effective for distances of 500–700 km than other forms of transportation; therefore, HSR routes shorter than 500 km without an extension plan should be reconsidered.

6.4. Location of HSR Station and Hubs

Following the analysis, HSR services have been made to benefit regional business and the nation's economy. Some of the most well-known HSR lines have completed at least two links between their main economic hubs. The service helps increase worker mobility and job relocation and is attractive for workers travelling from accommodation and workplaces. Moreover, the location of stations is a significant factor. A compelling conclusion from this research is that HSR stations and hubs should be interconnected with other forms of public transportation.

The planning should also include boosting retail areas, central business districts, commercial hubs, and tourism attractions. Offices and commercial spaces near the train terminals may contribute to a more robust business environment for employees. The findings clearly show that locations near major business districts serve as valuable employment resources by offering easy service to workers [27,120]. Moreover, workplaces being within walkable distance of HSR stations has become an essential criterion for job seekers. These significant areas can support future urban expansion and population relocation. The effective planning of such locations can reduce agglomeration in towns and disparities in society.

6.5. Intermodal Transportation

Some countries have planned effective HSR networks by linking them with transportation hubs and airports. This should be an effective measure for short HSR routes as they can offer alternative services to passengers. Moreover, the network can be integrated with other forms of public transportation due to increasing regional mobility.

These policy implications can be applied to all HSR networks, both existing and upcoming projects. The strategic creation of transportation policy could enhance the benefits related to various fields, such as spatial distribution, economic potential and QoL. These can provide positive impacts for people in all age groups.

7. Conclusions and Summary of the Key Findings

Ultimately, many scholars believe that HSR services may benefit the society, and several nations are considering building HSR networks. However, while HSR services undoubtedly generate significant socio-economic benefits, their effect may be exaggerated, not necessarily benefiting the whole population. Furthermore, this research has identified a knowledge gap in that there has been no previous evidence for the measurement of HSR's impacts on the young and older generations. Therefore, unparalleled big data sets have been adopted to determine the socio-economic effects through novel Python models.

The outcomes point towards young and older generations to gain lower benefits derived from HSR networks in some countries. This research highly recommends that HSR authorities and policymakers pay more attention to local HSR services on both groups, especially the PD2 and PD3 factors. It can reflect the life quality of the entire society, same as economic benefits. Moreover, the impacts of HSR on the country's economy has been reflected through the labour markets. This study highly recommends concern in the rate of employment (ED2 and ED3) after operating the HSR services in the area, as it reflects capabilities of overall country's economy.

The case study of five HSR networks' socio-economic effects has been analysed by using long-term data sets. Moreover, the KNN and PCC models have been applied using novel models to assess the sizes of social impacts. The benchmarking study results indicate that SNCF's and Renfe's networks have the highest advantages for all demographics. Those networks are followed by CR, Korail, and JR Central, where their social benefit schemes do well for the non-adult population and provide them with enough benefits, especially in terms of education as ED1, ED2, and ED3. This study is the world's first analysis of the educational usefulness of the HSR. The outcomes of this research are expected to provoke full benefit for all, leading to long-term improvement.

The expert opinion and feedbacks have been assembled from 30 railway experts globally to adapt our findings for a practical recommendation. The analysis for all networks except the Japanese network is higher than the 'agreed' level. In addition, these experts also prioritise policies and projects to increase the effectiveness of HSR networks as follows: providing access to important cities, connecting to various modes of public transportation or transportation hubs, and offering reduced or special tickets. By supporting a globally sustainable development policy, this study has aimed to assess and increase the socio-economic benefits from HSR services for both existing and upcoming networks. These policies point towards the advantages and practicability of improving socio-economic benefits for each society.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A. The Validation of PCC Analysis

Giving example of calculation of the PCC value of ED1 factor on CR network.

Given $P = \frac{\sum(X_i - x)(Y_i - y)}{\sqrt{\sum(X_i - x)^2 \sum(Y_i - y)^2}}$; X_i = ED values at year i, x = the average of the ED values; Y_i = length of CR network at year i; y = average length of CR network.

$$P = \frac{\begin{array}{c}(530-8027.18)(109.65-104.055)+(2753-8027.18)(109.36-104.055)+\\(3934-8027.18)(107.36-104.055)+(5352-8027.18)(105.91-104.055)+\\(7931-8027.18)(105.23-104.055)+(9086-8027.18)(103.88-104.055)+\\(10389-8027.18)(99.20-104.055)+(11091-8027.18)(99.33-104.055)+\\(11921-8027.18)(100.85-104.055)+(12643-8027.18)(102.85-104.055)+\\(12669-8027.18)(101.68-104.055)\end{array}}{\sqrt{\begin{array}{c}[\begin{array}{c}(530-8027.18)^2+(2753-8027.18)^2+\\(3934-8027.18)^2+(5352-8027.18)^2+\\(7931-8027.18)^2+(9086-8027.18)^2+\\(10389-8027.18)^2+(11091-8027.18)^2+\\(11921-8027.18)^2+(12643-8027.18)^2+\\(12669-8027.18)^2\end{array}]+[\begin{array}{c}(109.65-104.055)^2+(109.36-104.055)^2+\\(107.36-104.055)^2+(105.91-104.055)^2+\\(105.23-104.055)^2+(103.88-104.055)^2+\\(99.20-104.055)^2+(99.33-104.055)^2+\\(100.85-104.055)^2+(102.85-104.055)^2+\\(101.68-104.055)^2\end{array}]\end{array}}}$$

$$P = \frac{-147798.125}{160590.681} = -0.92$$

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