Invited paper - Highspeed rail systems

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Highspeed rail systems: A new international benchmark for safety and its influence on supply chains

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1. Introduction

The world's first highspeed rail systems have been built and operated in Japan since 1964. Commonly, the term 'highspeed' implies a train speed over new rail lines in excess of 250 km/h (155 mph), and over upgraded existing lines in excess of 200 km/h (124 mph). Interestingly, high-speed rail (HSR) infrastructures have been constructed in several countries in order to improve the connectivity between major cities. A report by International Union of Railway [1] shows global HSR development in Belgium, China, Denmark, France, Germany, Italy, Japan, Morocco, the Netherlands, Poland, Russia, Saudi Arabia, South Korea, Spain, Sweden, Taiwan, Thailand, Turkey, the United Kingdom, the United States and Uzbekistan. Table 1 illustrates the summary of the HSR infrastructure internationally [1]. Apparently, the operational demands in Asia dominate HSR services around the world. The world's largest HSR networks in operation are in China, who has built over 38,283 km of high-speed rail (with 14,925 km under construction as of 1 June 2021), accounting for more than two-thirds of the world's total. The maximum operational speed of 350 km/hr can be seen in China. Note that high-speed rail networks across international borders are predominantly in Europe, and fewer in Asia (i.e. China-Laos).

Table 1 Summary of global highspeed rail infrastructures.

Area	Length (km)*				
	In operation	Under construction	In planning stage	Future aspiration	Total
Africa	186	0	2,010	2,690	4,886
Asia Pacific	42,217	16,515	7,357	18,320	86,235
Europe	11,819	2,405	5,399	3,482	23,241
Latin America	0	0	0	638	180
Middle East	1,173	3,079	2,146	1,831	9,572
North America	735	563	1,869	6,044	7,688
Total	**56,129**	**22,562**	**18,781**	**33,005**	**131,803**

*data updated on 1 June 2021

Given the stronger expectation for net zero transport alternatives [2-4], rail services have gained more public trust and demands to enable both short- and long-distance connectivity. Despite the fact that HSR services are among the least contributors to carbon emissions, their actual service performance is relatively unknown and cannot be commonly assessed in real life. With a business goal in mind, many rail operators maximise every opportunity for their business marketing via every platform from contemporary advertisements, digital & social media campaigns, to influential YouTubers. Every business spends multi-millions of dollars in self-marketing their own products and services. These company marketing practice could mislead and provoke the public expectation and customer experience by inducing exaggeration and/or overly promised quality perception. Without an unbiased and fair performance assessment framework, best practices in rail business cannot be quantitatively identified and further improved to enhance true public safety, operational reliability, customer experiences (e.g. ride quality, passenger services, etc.), and business efficiency and effectiveness (e.g. value for tax payer money). On this ground, there is a serious need to establish an innovative approach and framework of comparing best industry practices against its organizations' processes to identify performance gaps and achieve a competitive advantage. In business, benchmarking has been instrumental in improving the performance of business. Benchmarking can be applied against any process, approach, function, or product in business and rail industry is not exempted. The process primarily focuses on measures like quality, time, cost, effectiveness, and the satisfaction of customers to distinguish what, who, how, and where there are problems. Benchmarking can be a valuable process for rail businesses in determining the good policy implementation and whether railway sectors create services and positive outputs that are value for money and/or for governmental subsidy.

There is a real danger when there is no benchmarking that a rail company may mislead the public and the government as an industry leader and that a rail company may still retain ineffective and inefficient practices. Without knowing exactly how other rail competitors are performing can give any rail company a false self-perspective; and can deteriorate the quality of its products and services. In this study, we have thus proposed a new international benchmarking framework to assess the operational performance of highspeed rail systems. Of a particular focus, railway safety has been the primary concern by the public and will be a prime factor for benchmarking in this paper. The benchmarking framework adopts the official data published by rail regulators and governmental statistics bureaus. It is important to note that the framework can assess any HSR systems globally. However, for demonstrations in this study, five notable rail networks have been selected as case studies including China, France, Japan, Spain and South Korea. In addition, this paper will address the sensitivity of HSR development on supply chains using the HS2 development in the UK as the case study. This highlights the evaluation of the possible impact of the HS2 project on supply chains through the air-rail-road freight transportation and logistics, to consider business opportunities and potential synergies. The focus in study underpins the United Nations' Sustainable Development Goals (i.e. 'Good Health & Well-Being', 'Industry, Innovation and Infrastructure', and 'Sustainable Cities & Communities').

2. Benchmarking HSR safety performance

Bayesian inferences has been employed to solve the information scarcity problem in some cases. Our research gathers long-term secondary passenger train accident data sets from railway regulators' and railway companies' official reports. First of all, data collection and data cleansing processes are required, focusing in details only on passenger train accidents. The data cleansing process for railway accidents includes stages to remove invalid data sets, match rail authorities' published documents, and recheck missing data sets. Fig. 1 illustrates the benchmarking process for HSR safety performance through complex risk models [5-8].

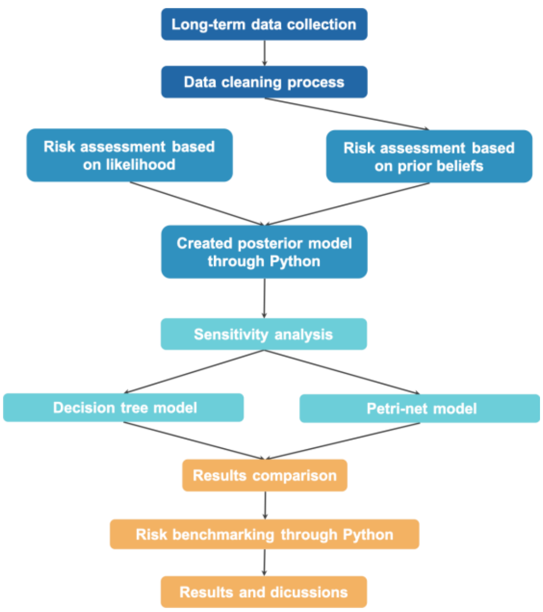


Fig.1 The next generation benchmarking framework for HSR safety performance and risks

Regarding the risk models, there are three crucial factors involved: number of passenger fatalities, number of passenger injuries, and type of railway accident. The risk score has been rated between 1 (lowest) to 32 (highest), broken down into four levels: low risk, medium risk, high risk, and extremely high risk, as illustrated in Fig. 2.

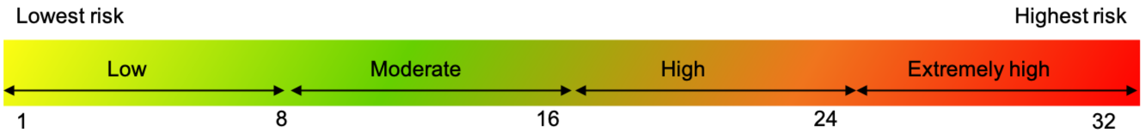


Fig.2 A determination of the risk score

The benchmarking results across the five HSR networks are provided in Table 2. These outcomes give a significant advantage because safety policies can be immediately adopted from those of 'low risk' networks for upcoming projects. Using the models, the railway company can precisely understand its situation, leading to enforcing effective policies to mitigate risks from the network. The risk level analysis results show that South Korea's railway system has the greatest risk among these selected countries. The safety level of South Korea's network has score at 18 that classifies as 'high risk'; whereas, France's network has a score of 10, which is in the 'moderate risk' range. China's, Japan's and Spain's railway systems have scores of 2, 2 and 7, respectively, which are in the 'low risk' range. Note: the benchmarking is currently extended to other HSR networks globally.

Table 2 Ranking of highspeed rail (HSR) safety performance

Rank	HSR Network	Risk Level	Bayesian Risk Score
1	**Japan**	**Low**	**2**
1	**China**	**Low**	**2**
3	Spain	Low	7
4	France	Medium	10
5	South Korea	High	18

3. HSR development and Supply Chains

There are various definitions for logistics and supply chains. 'Supply chain' is often used to describe 'the management of upstream and downstream relationships with suppliers and customers to deliver superior customer value at less cost to the supply chain as a whole'. Different types of supply chain complexity are illustrated in Fig. 3.

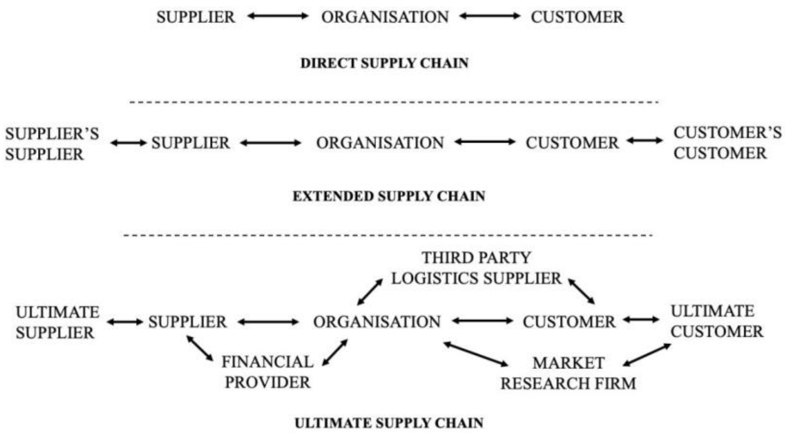
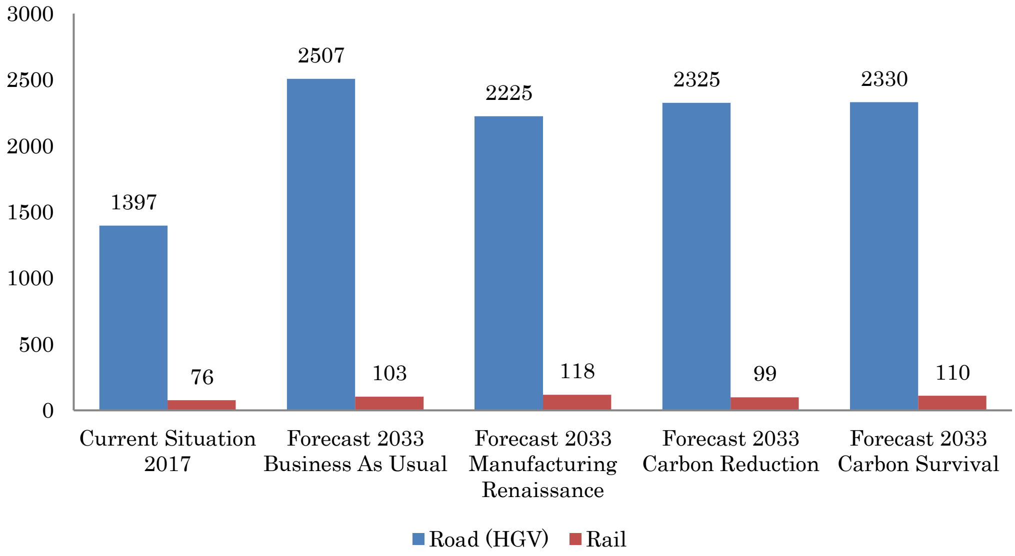
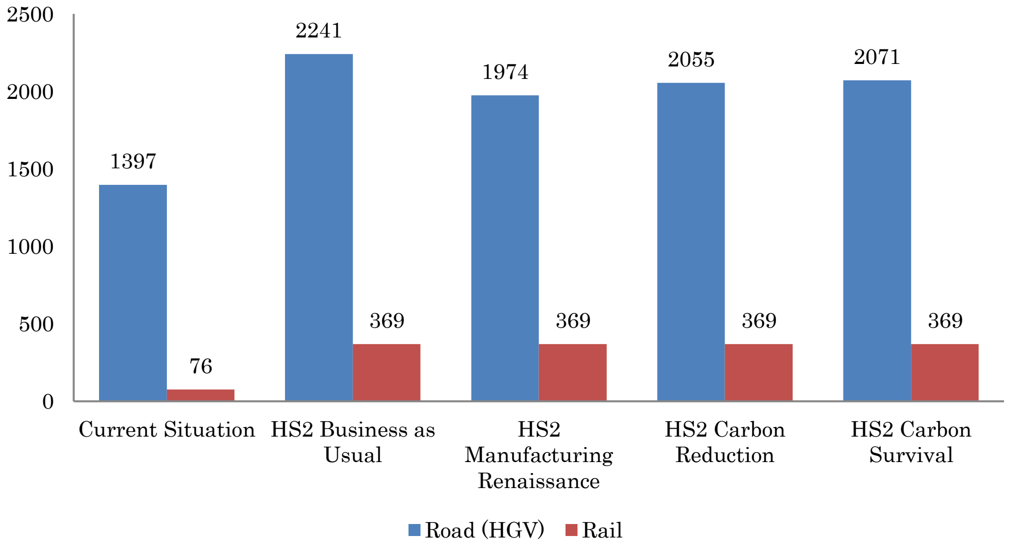


Fig.3 Complex interaction of supply chains

Shifting freight from road to rail may have a positive effect on the haulage industry and could reduce congestion on the roads. The share of railway freight is noticeably smaller than that of road transport, therefore there is a probability that changes could be insignificant. The performance of rail freight transportation has a large potential to solve related to overall effectiveness, empty running and loads of railway carriages which could be improved by the application of IT, new technologies and modern management techniques. A framework for measuring the performance of a supply chain is presented in [9]. Cost analysis for rail and road freight transportation shows that the maximum price for road transport is for the 'Business as Usual' and 'Carbon Survival' strategies, which could be caused by the overall consumption of goods, there being no ban on diesel, and tax increases. The minimum cost for rail freight haulage is under the 'Carbon Survival' strategy, probably because of a shift to electric engines, technological development and tendencies in the market. In Fig. 3, the comparison of freight and passenger rail usage in values of rail vehicle kilometres shows that the existing system could be used for freight hauling by 4.85 times more than currently. Analysis of capacity shows that after the HS2 construction, from 14 to 16% of freight could be moved by rail; whereas without this project it may remain at 5% of the overall amount. The biggest part of freight is moved by road transport, while airfreight is accountable for the smallest share of the market, which is less than 1%. Shares of the market for rail and road modes of freight transport for different strategies and for different strategies for the HS2 case are illustrated in Fig. 4.



a) freight lifted by traditional transport modes



b) freight lifted by transport mode HS2 case

Fig.4 Sensitivity of supply chain due to the development of HS2 scenarios (unit: million tons).

Table 3 Supply chain risk framework

Stakeholders	Expectations	Risks
Freight transport operators	1) Congestion-free infrastructure 2) Efficient goods delivery and collection 3) Low-cost of transportation	1) Freight share insignificance 2) Lack of efficiency growth in comparison with the current situation
Shipper	4) On-time deliveries to customers 5) Cost-effective transport service	3) Insensible effect on customer experience 4) Possible charges for the service at logistics Centres 5) Late delivery due to congestion
National Government	6) Efficient use of strategic infrastructure 7) Efficient goods delivery and collection 8) Minimising externalities (CO2, air quality, congestion)	6) Insensible growth of efficiency 7) Little effect on road congestions due to rail freight share insignificance
Infrastructure providers	9) Congestion-free infrastructure 10) Maximising revenue	8) Little effect on road congestions due to rail freight share insignificance 9) Growth of expenditures/taxes
Citizens	11) Availability of variety of goods 12) High quality of life	10) Insensible effect on customer experience 11) Overcrowded trains, noise from business/logistics' centres around
Customers	13) On-time deliveries 14) Short lead time	12) Insensible effect on customer experience, increased delivery cost 13) Insensible growth of lead time
Local government	15) Well-being of residents 16) Efficient use of local infrastructure 17) Efficient goods delivery and collection	14) Noise and congestions around business/logistics' centres or railway path 15) Negative impact on uninterested stakeholders, business shift 16) Lack of efficiency growth in comparison with the current situation

The HS2 construction will accompany transport hubs' development and may stimulate the creation of new logistics centres that could directly affect companies' planning. Reliable transport and warehouse accessibility allow increasing inventory turnover; this contributes to profitability, and hence flexibility, so responsiveness metrics are evaluated as enhanced [9]. It is possible that changes associated with customers would not be significant and may depend on information exchange about their deliveries. Modern technologies nowadays enable this to be carried out at relative high level, but could be improved with overall industry development. Risks identification presented in Table 3 is based on stakeholders' expectation failure. The proposed level of demand and load shows that the share of rail freight would be noticeably smaller, consequently freight haulage as an industry could receive less significant benefits than passenger transportation. Note that this supply chain analysis has not taken the effect of coronavirus into account [10]. Such effect can be incorporated in the model in the future.

4. Conclusions

With the growth of HSR and rail networks worldwide, safe rail services are a key driver for railway operators in supporting passenger journeys. Based on the long-term accident data sets, rail accidents can be classified into three groups: collisions, derailments and other effects. This study has found that the 'other effects' category caused four times more damage than collisions and derailments. Therefore, the research has analysed the accident data sets through novel models and has selected best practice. This research aims at understanding the uncertainties of railway accidents to precisely reduce the impact of casualties. In terms of benchmarking risk levels, five countries have been selected: China, France, Japan, South Korea and Spain. The research has developed a 'benchmarking risk' model, which is a linear transform model based on posterior probability, and the severity levels of injuries and fatalities. The benchmarking results illustrate that China's, Japan's and Spain's networks are in the 'low risk' category, while France's network is 'moderate risk' and South Korea's network is 'high risk'.

Our study also investigates air-rail-road freight transportation and logistics to determine the possible effect of the HS2 project's construction on supply chains. The overall results indicate favourable but slight changes with a high potential for improvement. In particular, the capacity evaluation points out the growth of the rail freight transportation's share from 5% to 14-16%, which could contribute to a decrease of road congestion. For choosing the most economical loop, HS2 can be seen as the most possible solution. Information is derived by comparison of the data from government reports and industries' forecasts. To identify suitable methods for supply chain analysis, relevant studies are considered and a risk framework for performance measurement is chosen as the appropriate investigation approach. Alterations in performance do not seem to be directly linked to the HS2 railway construction and rather associated with infrastructure and technologies' development.

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