The Total Social Costs of Constructing and Operating a High-Speed Rail Line Using a Case Study of the Riyadh-Dammam Corridor, Saudi Arabia

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This paper builds on an earlier paper by the authors on the potential for "The total social costs of constructing and operating a maglev line using a case study of the Riyadh-Dammam corridor, Saudi Arabia" (Almujibah and Preston, 2018) by examining High-Speed Rail.

Keywords: High-Speed Rail, Total Social Costs, Operator Cost, User Cost, External Cost, Saudi Arabia

ABSTRACT

Constructing High-Speed Rail technology between the Saudi Arabian cities starts raising many challenging issues of a different nature ranging from technical to operational, which require huge investments in infrastructure, operations and maintenance.

However, this paper develops a new methodology to calculate the total social costs of building a new HSR worldwide and applies this using the case study of the Riyadh-Dammam corridor in Saudi Arabia. This is done through a Spreadsheet Cost Model mainly based on Microsoft Excel that includes operator cost, user cost, and external cost.

In order to determine the total social costs of a Riyadh – Dammam HSR line, the annual travel demand is forecasted of 13,205,212 passengers in the first year of operation. In this case, the gravity demand model is used to forecast the demand, as a function of independent variables for the cities alongside with the proposed line such as the population, GDP per capita, the generalized journey time, unemployment rate, years since opening the corridor, and the dummy variable.

As a result, the total social costs of constructing and operating the proposed HSR line is €1,090,106,913 per year resulting from the sum of the following categories. First, the total operator cost is €859,797,307 per year, which is mainly based on the total infrastructure and rolling stock costs of €750,852,759 per year and €108,944,548 per year, respectively. Second, the total user cost is €216,769,247 per year resulting from the sum of total annual passenger access/egress time, waiting time, and in-vehicle time. Finally, the total external environmental cost is €13,540,359 per year resulting from the sum of average costs of noise and air pollution, climate change, and accident.

I. INTRODUCTION

High-Speed Rail (HSR) is defined as a technical subject and complex reality, comprised of different various technical elements such as infrastructure (new lines designed to run at a maximum speed of **250 km/h or more**), rolling stock (special designed train sets), and operations rules, maintenance systems, etc., using highly sophisticated technology (International Union of Railways, 2017a). HSR is also described as the "transport mode of the future" and that is due to three main characteristics, including safety, capacity and sustainability that are offered to customers and society (Angoiti, 2010). High-Speed Rail has become an important technological achievement and a symbol of efficiency, besides being a new transportation mode for passengers in the 20th century (Campos, De Rus and Barron, 2007b).

The global HSR is rapidly expanding worldwide across continents, delivering fast and efficient mobility to numerous nations every day. Currently, HSR is in operation in more than 16 countries, including Japan, France, Germany, Spain, Belgium, United Kingdom, South Korea, Italy, Taiwan, China, Saudi Arabia, and the Netherlands. Additionally, HSR is in under construction in Iran, Morocco, USA, Switzerland, Mexico, and other countries in the world. As of January 2019, the total length of HSR networks in operation worldwide is 45,996 kilometres, divided between 14 Asian countries, 17 European countries, and 8 other countries. Table 1 shows the countries with an HSR in operation or under construction, with the total length of their network, while China has the largest network of HS services worldwide.

Country	In operation (km)	Under construction (km)	Total network (km)
China	31,043	7,207	38,250
Spain	2,852	904	3,756
Japan	3,041	402	3,443
France	2,814	0	2,814
Germany	1,571	147	1,718
Turkey	594	1,153	1,747
Italy	896	53	949
South Korea	887	0	887
USA	735	192	927
Saudi Arabia	453	0	453
Iran	0	787	787
Taiwan	354	0	354
Belgium	209	0	209
Morocco	200	0	200
Switzerland	144	15	159
The Netherlands	90	0	90
United Kingdom	113	230	343
Denmark	0	56	56
Total	**45,996**	**11,146**	**57,142**

Table 1: Overview of HSR network by country in 2019

Source: (International Union of Railways, 2019)

In HSR projects, the investment may be one of the measures that leads passenger transport volume to shift from other modes such as road, air transport to rail, and that would help to reduce the congestion, balance the modal split and decrease environmental negative impacts. In this case, building high-speed lines requires high-quality infrastructure and that could cause more costly investments than conventional railways but a change in generalised travel costs when it comes to journey time can be considered (Gorlewski, 2011). However, the building, operating and maintaining HSR lines mainly involves an important total of costs that deal with the development plan of the transport sector and the transport policy of a country. In Europe, three different types of lines developed for high-speed infrastructure: building new high-speed lines, upgrading existing conventional lines for speeds of 200 km/h, and upgrading conventional lines for speed that must be adapted to each case same as in Germany of the fully mixed model. In this case, four different exploitation models have been identified as shown in Figure 1.

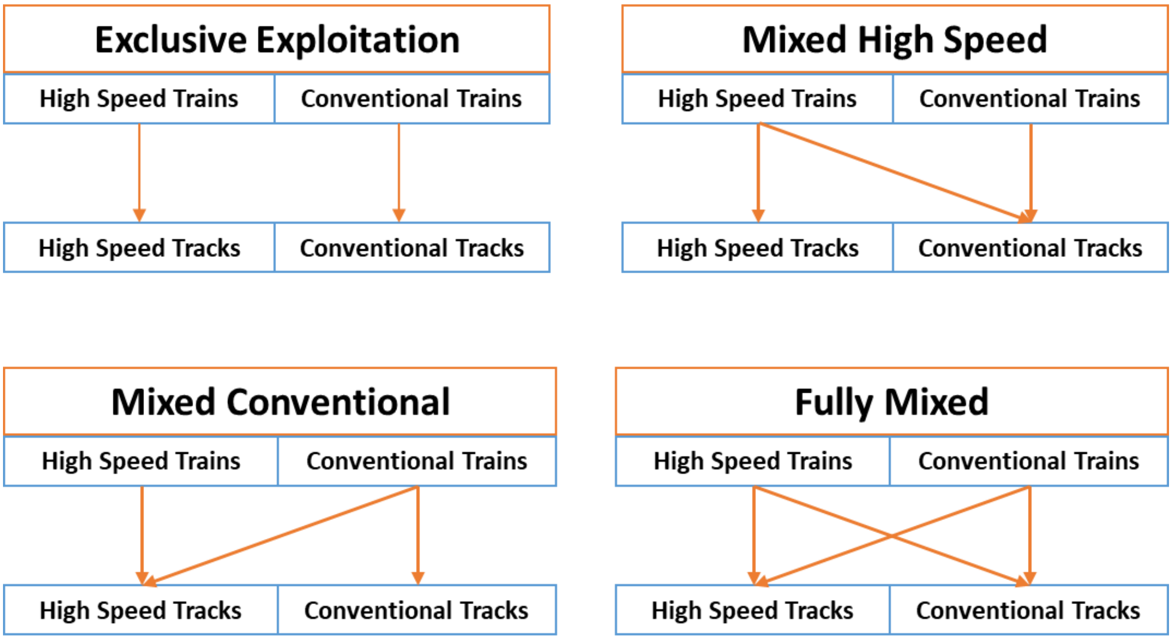

Figure 1: High-speed degrees of separation
Source: (Rutzen and Walton, 2011; De Rus, 2012)

First, the Japanese Shinkansen model is considered by a full division of infrastructure between HSR and conventional rail services. Shinkansen lines adopted this model since 1964 due to the increasing capacity constraints in the existing conventional lines that were built in narrow gauge (1067 mm), as formed by the geological and geographic features of the country. On the other hand, the Japan National Railway (JNR), decided to design and build the new high-speed lines in standard gauge (1435 mm), as well as the market of HSR and conventional rail services are completely independent (Campos, De Rus and Barron, 2006). Second, France is a good example of the mixed high-speed model that has been operated by TGV (Train a Grande Vitesse) since 1981, where high-speed trains can run either on specific newly built lines or on upgraded conventional lines at lower speed.

In this case, a number of passengers will be switched from conventional trains as the HSR is servicing a larger network and more railway stations. Thirdly, the mixed conventional model is used in Spain, in which some conventional trains can use the high-speed tracks. In addition, this model has been operated by Spain AVE (Alta Velocidad Espanola), where some of the Spanish conventional trains were built in broad gauge (1,676 mm). For example, the Talgo trains have been developed, as a specific adaptive technology for rolling stock to facilitate the interoperability of international services and use at a higher speed than normal at the specific HSR infrastructure (De Rus, 2012). During the period between 1992 and 2008, the developed technology allows trains to transfer between different rail gauges. However, the new rolling stock can transfer from conventional lines to a high-speed line without stopping and expanding the mixed HSR services to include an increased number of places, especially cities where the

HSR infrastructure has not yet been built (De Urena, 2016). As a result, the main advantage is the saving costs for the acquisition and maintenance of rolling stock, and "the flexibility for providing intermediate high-speed services on certain routes". Lastly, the fully mixed model that is used in Germany and Italy for the maximum flexibility where both HSR and conventional trains can run on each type of infrastructure (De Rus, 2012). In Table 2, China high-speed rail network had carried about 464.1 billion of passengers per kilometre in 2016, as the highest number of traffic demand in the world whilst Taiwan HSR transported the lowest number of traffic demand of 10.5 464.1 billion of passengers per kilometre (International Union of Railways, 2019).

Year	2010	2011	2012	2013	2014	2015	2016
China (China Railway)	46.3	105.8	144.6	214.1	282.5	386.3	464.1
Japan (JR group)	76.9	79.6	84.2	78.4	89.2	97.4	98.6
Other European Companies	70.8	74.9	78.2	78.8	81.6	82.7	84
France (SNCF)	51.9	52	51.1	50.8	50.7	50	49.1
Germany (DB AG)	23.9	23.3	24.8	25.2	24.3	25.3	27.2
South Korea	11	13.6	14.1	14.5	14.4	15.1	16.3
Spain (Renfe Operadora)	11.7	11.2	11.2	12.7	12.8	14.1	15.1
Italy (Trenitalia)	11.6	12.3	12.3	12.8	12.8	12.8	12.8
Taiwan High Speed Rail	7.5	8.1	8.6	8.6	8.6	9.7	10.5

Table 2: High Speed traffic in the world (billion passenger-km)
Source: (International Union of Railways, 2017a)

II. OVERVIEW OF HIGH-SPEED RAIL TECHNOLOGY

A. High Speed Rail in Various Countries

1) Japan

Japan is considered for large cities in terms of a densely populated country with a surface area of approximately 380,000 square kilometres and a total population of 128 million in 2015 (Statistics Bureau, 2016). In 2015, Japan was the third largest economy in the world, having a gross domestic product of €3.69[1] trillion and GDP per capita of €27,879 (International Union of Railways, 2017b). In the building of high-speed rail, Japan was an inventor in the world and the decision in the development of the high-speed rail network in Japan known as the Shinkansen was made after the conventional line (for both passenger and freight) had become very congested, meaning that more capacity was needed. However, the first line in its network came into service in October 1964 with a length of 515 kilometres, linking two largest cities in the country, Tokyo and Osaka for an operating a speed of 210 km/h (International Union of Railways, 2017b). In terms of ATC, it is a safety mechanism system used along the entire network of the Tokaido Shinkansen to display a maximum speed limit to the driver. It also automatically applies the brakes if the driver exceeds the speed to slow the train to its allowable speed (JR-Central, 2017). In this case, the Shinkansen has a perfect of safety record, with no train for more than 50 years since the first line commenced operation. It also has first-rate punctuality with an average delay of less than 1 minute per train (0.2 minutes per train). For example, the Tokaido Shinkansen connects three largest metropolitan cities in Japan, Tokyo, Nagoya and Osaka, for a high-frequency service of 358 trains per day (10 trains at peak hours from Tokyo), carrying around 445,000 passengers per day in 2016 compared to 61,000 passengers in 1964 (JR-Central, 2017). Currently, the Japanese Shinkansen has nine high-speed

[1] Convert rates used in this paper 1€=1.22$ and 1£=1.13€

lines with a total network of 3,041 kilometres in operation, and 402 kilometres under construction (International Union of Railways, 2019).

Due to the high rate of earthquakes in Japan, slope protection, seismic reinforcement of infrastructure, and wind barriers and erection of avalanche fences were used for the HSR infrastructure construction, including tunnelling and technical challenges to reduce the risks of natural disasters (Palacin et al., 2014).

2) France

France is located in Western Europe, and with a gross domestic product of €1.815 trillion, it ranks 10th in the world and €28,688 of GDP per capita in 2015. The development of HSR system in Japan was watched closely by France, as the French National Railway (SNCF) needed to provide extra capacity on the main line connecting two largest cities, Paris and Lyon. Offering faster services was also considered and it decided to adopt the Japanese Shinkansen approach of building an HSR line on a new alignment. In 1981, France became the first country in Europe providing HSR service that was opening between Paris and Lyon known as TGV Sud-Est for a distance of 419 kilometres in about 2 hours, followed by other HSR lines (TGV Atlantique, TGV Mediterranee and TGV Rhone-Alpes, TGV Nord, TGV Est) (Amos, Bullock and Sondhi, 2010; International Union of Railways, 2010b). France has longer HSR corridors serving small cities with a lower demand; the population of the country is more distributed. In France, a dedicated line for passenger traffic, high-frequency operations with short travel times, and integrating HSR with existing railway network were three principles related to the defining concepts of the first HSR line, as it was the lowest in terms of the construction cost per kilometre. In this case, achieving high operating speeds, reducing the costs of constructing, operating, maintaining new HSR lines and rolling stock, and optimizing capacity are factors that are based on traffic growth and contributed to the increased profitably of HSR systems. For example, the TGV Mediterranee with seven long viaducts and one long tunnel of the length of 17 and 13 kilometres respectively cost only €12.29 million per kilometre compared to the cost of the first TGV Sud-East line that was just €3.28 million per kilometre (Arduin and Ni, 2005).

3) Germany

Germany is located in Central Europe and maintains the largest economy in Europe, with a GDP of €2.53 trillion and €31,065 of GDP per capita per year. In Germany, there was a consideration between the Ministry of Transport and the Centre of Railway Management centred at the beginning, on an issue of whether building new lines should be following the Japanese and French Model on being dedicated only to passenger traffic or it would be best to mix passenger and freight traffic (Ebeling, 2005). HSR lines were developed by the German federal transportation in at the beginning of 1970, in order to increase the level of congestion on the existing rail network and make the rail competing with other transport modes. However, the first HSR line was built to accommodate a conventional passenger train service at a speed of 200km/h, while newer lines run with the fastest speed up to 300 km/h.

The HSR system known as Intercity Express (ICE), has a total of 1,475 kilometres in operation and 437 kilometres under construction (International Union of Railways, 2010c). In Germany, the Deutsche Bahn (DB) holdings manage the operation of passenger and freight rail, which was found in 1994 and it operates ICE trains outside of Germany. On the other hand, the finance of constructing HSR lines comes mostly from the federal government, as well as from local and state governments. The ICE is also designed to connect markets to the main cities inside and outside the country, as the ICE service is already provided to major European cities such as

Paris, Brussels and Amsterdam, and it intends to expand the service between Frankfurt and London (International Union of Railways, 2010c). In Table 3, the German ICE system has shown steady growth, as it was carrying about 74 million passengers in 2009, compared to 5,100 million passengers during the first year of its operation (1991).

Year	Passengers (thousands)	Passenger-km (million)
1991	5,100	2,000
1997	30,947	10,073
2001	46,668	15,515
2009	73,709	22,561

Table 3: Germany's High –Speed Rail Passenger Traffic
Source: (International Union of Railways, 2010c)

In 1998, Germany had the worst HSR accident in the world close to the village of Eschede that is located in Celle district of Lower Saxony, as an HS train derailed and crashed into a road bridge with the impact of 101 fatalities and 88 injuries (Janic, 2017).

4) Spain

Spain is located in Southwestern Europe, with a GDP per capita of €25,966 in 2016 and 3% of an average annual growth (Ortega Hortelano, Almujibah and Preston, 2018). In Spain, the first HSR line was opened in 1992, connecting Madrid, Cordoba and Seville, stretching from the centre of the country to the southern side of the Iberian Peninsula for a length of 471 kilometres, while Seville hosted the Universal Exposition in April 1992. The HSR service is called Alta Velocidad Espanola (AVE) and operated by Renfe Operadora, the state-owned railway company. On the other hand, the railway infrastructure is managed by another state-owned company called ADIF, as Spain has rapidly expanded its high-speed service network since the opening of the first HSR line. As shown in Table 7, Spain's HSR has a network length of 2,852 kilometres in operation and 904 kilometres under construction, and that makes Spanish HSR network the longest in Europe and operates at a maximum speed of 310 km/h (International Union of Railways, 2019).

In Spain, the development of a high-speed network has been largely financed and funded by government and European Union sources. In this case, Spain took advantage of European funds after joining the EU in 1986 to develop its HSR network. However, the first high-speed rail line was built based on the technical standards of the French high-speed network (TGV) with a standard gauge of 1435 mm (Hortelano et al., 2016). Due to entering a bend at an excessively high speed, an HS train operating on the Madrid-Ferrol route derailed in 2013, as the allowed speed of 80 km/h was doubled. This accident took place about 4 kilometres outside the station of Santiago, which is located in the northwest of Spain with the impacts of 79 fatalities and 139 injuries (Janic, 2017). In Table 4, the Spain AVE system has shown steady growth, as it was carrying about 28,751 million passengers in 2009, compared to 1,314 million passengers during the first year of its operation (1992).

Year	Passengers (thousands)	Passenger-km (million)
1992	1,314	400
1997	4,032	1,266
2001	6,998	2,409
2009	28,751	10,490

Table 4: Spain's High –Speed Rail Passenger Traffic
Source: (International Union of Railways, 2010d)

5) United Kingdom

The United Kingdom is located in Western Europe on an island off the coast of Belgium and France, with a GDP of €1.84 trillion and €29,426 of GDP per capita per year. The idea of the HSR service in the UK went to 1998, as the line was originally planned to be constructed in a single project but it was restructured and divided into two sections due to financial difficulties. In 2003, the first HSR line was opened in the UK between the Channel Tunnel and London, called HS1, as its segment provides direct international service to Paris and Brussels. The first section runs from the Channel Tunnel to Fawkham Junction over a distance of 75 kilometres and has an operating speed of 300 km/h. Moreover, this section cost €2.16 billion and opened to passenger traffic in 2003 on time and on budget. On the other hand, the second section was opened in 2007, connecting the Southfleet Junction into central London's St Pancras Station with a cost of €3.75 billion (International Union of Railways, 2010e). This line is the most expensive HSR line ever built in the world due to its lengthy tunnelling that was constructed to avoid environmental objections (Nash, 2010). With the opening of the HS1, travel times were mostly reduced, as it is only taking more than two hours from London to Paris and fewer than two hours from London to Brussels.

In 2009, HS2 was formed by the Department of Transport to develop plans for new HSR network, connecting London to Birmingham for a distance of 205 kilometres in the first section. In addition, two segments are included: one from London to Manchester and the other to Leeds in the second section for a distance of 335 kilometres, with an operating speed of 360 km/h for whole HS2 network (International Union of Railways, 2010e). In this case, HS2 will be used separately by high-speed passenger trains, as it will be possible to have 18 train paths per hour and each train will be designed to provide a capacity for 1,100 passengers. The costs for the first section of HS2 route would be between €17.9 billion and €19.8 billion whilst the second section would cost a total of about €34.1 billion in 2009 prices. In the second section connecting London to Manchester and Leeds, some unit rates per kilometre were used over undulating terrain (€19.9 million), over flat terrain (€18.5 million), in the tunnel (€90.8 million) and through urban areas (€28.4 million) (Preston, 2010).

6) China

China is located in the continent of Asia, as the fourth largest country in the world in terms of area with a GDP of €9.25 trillion and €6,885 GDP per capita. In China, the Chinese HSR network is owned, developed and operated by the Ministry of Railways (MOR) whilst the first HSR line was opened in 2003 between Qinhuangdao and Shenyang for a length of 405 kilometres and operating at a speed of 250 km/h (International Union of Railways, 2010a). As shown previously in Table 1, China has the largest HSR network in the world with a total of 31,043 kilometres in operation and 7,207 under construction due to strong government support and regular investment. Due to the rapidly growing HSR network in China, it is larger than the combined HSR networks of 17 European countries (8,948 kilometres) and accounts for nearly 65% of all HSR lines in the world (UIC, 2017). By 2020, the Chinese HSR lines will connect 192 of prefectural level cities with around 783 stations and more than one station is necessary to build on the network in many cities due to a very high passenger (Chen, Tang and Zhang, 2014).

China is the world's most populated country, with a population of about 1.4 billion. In this case, one of its main reasons of developing Chinese high-speed rail (CHSR) is to reduce the gap between the relatively limited capacity of the railway network and the large social transportation demand, especially during the holiday. On the other hand, the cost of building a high-speed line with a speed of 300 km/h is about three times higher than a conventional rail line. For example, the investment of actual total infrastructure building the intercity high-speed line between Beijing and Tianjin was €2.63 billion for a length of 118 kilometres, while the total investment of the Wuhan-Guangzhou high-speed line for a length of 1079 kilometres was €3.44 billion (Chen, Tang and Zhang, 2014).

7) **Saudi Arabia**

The Kingdom of Saudi Arabia is one of the richest developing countries in the world, and its economic wealth primarily comes from revenues of oil, which changed the kingdom from a pre-industrial to a modern industrial country (Al-Ahmadi, 2006). It is located in the Middle East on the Arabian Peninsula between the Red Sea and the Persian Gulf, and ranks the 13th largest country in the world based on land area (2.15 million square kilometres). The Saudi Railway Master Plan (SRMP) related to the development of rail line projects are classified into three phases of development, with the first phase covering the years 2010 to 2025; the second phase covering the years 2026 to 2033; and the third phase covering the years 2034 to 2040. In this case, the project of the first high-speed rail in Saudi Arabia, Haramain High-Speed Rail (HHSR) was considered high priority, as it is linking the two holy cities, Mecca and Madina via Jeddah and King Abdullah Economic City (KAEC) in Rabigh with a distance of about 450 km and a maximum operating speed of 300 km/h. Moreover, each train has a total length of 215 m including 13 cars with two-power cars generating a combined output of 8MW to provide 417 seats (Ferran, 2017).

The total construction costs of HHSR were about €13.5 billion, including civil works, construction of stations, railway systems and rolling stock, and project management (Arabnews, 2017b). One of the main reasons that led the Saudi government to build the HHSR is due to the growing number of yearly pilgrims, Umrah visitors and residents who come to Mecca and Medina during the year. Another reason is to relieve congestion and reduce air pollution from vehicle exhaust on roadways between the cities. The HHSR will reduce the travel time between Jeddah and Mecca to 30 minutes and between Mecca and Medina to 2 hours. In addition, many European rail infrastructure companies and rolling stock manufacturers had been involved in this project in a result to transport a significant share of more than 11 million pilgrims and visitors that travel to and from the two holy cities.

Moreover, this project will link the cities' centres, boosting local business and tourism along the line, as there are 35 high-speed trains that were designed and manufactured by Talgo with the most advanced safety systems and there is an option of supplying 20 more. Each train has 13 cars providing 417 seats with a total length of 125 meters. On the other hand, the line is equipped, operated and maintained for 12 years by Renfe, which is one of the Spanish Al-Shoula consortium members[2]. As a result, Rumaih Al-Rumaih, Chairman of the Public Transport Authority (PTA), announced that the official opening date of HHSR project for March 2018, even though the project was originally due to open in 2012 but has been affected by cost increases of €150 million and delays (Aguinaldo, 2017; Llie, 2017). On 25th of September 2018, Saudi Arabia's King Salman has officially inaugurated the HHSR with initially operating eight trips per day in both directions for a fleet of 35 trains. In this case, the

[2] The Spanish Al-Shoula consortium comprises 14 companies, with two Saudis in the Saudi Al Shoula and Al Rosan and 12 Spanish, which are Adif, Ineco, Renfe, Cobra, Copasa, Consultrans, Imathia, Inabensa Indra, OHL, Siemens and Talgo.

first train will depart on fourth of October from Mecca to Medina via Jeddah center station and King Abdullah Economic City whilst the service to Jeddah Airport is scheduled to commence by the end of March 2019 (Aldroubi, 2018).

B. Advantages and Disadvantages of High-Speed Rail

According to Rutzen and Walton (2011), there are direct social advantages of HSR systems, such as time savings for passengers, reduction in accidents, increase in comfort, reduce the delays and congestion in airports and roads, and reduction in environmental impacts.

Time savings are one of the main factors when considering competition between other modes. The perceived value of the benefits will depend on a number of elements, including whether the trip is for work or leisure, and the mode used to access the HSR station. Furthermore, time saving is related to mean journey length, value placed on travel time saving and relative door-to-door speeds, and the value of time is usually higher for business journeys than leisure or commuting journeys. In this case, the proportions of HSR travellers that are business users and trips that are generated can be determined as important variables (Preston, 2009).

The value of time of passengers is a dominant factor, and the convenience influences appear to be larger for business travel than for commuting. However, neighbourhoods around major urban centres that are served by HSR can enjoy the accessibility benefits of HSR and transfer easily to and from the conventional railway network, while places along a HSR line might suffer lower accessibility levels by being avoided (Brunello, 2011). For example, in Spain, the advantage of HSR makes some cities such as Madrid, Cordoba, Toledo, Seville, and Barcelona more accessible and much easier for tourists to visit (Loukaitou-Sideris and Peters, 2015). However, the largest deviations come from conventional trains and planes, while the access, waiting, in-vehicle and egress times are distinguished beside time savings (Albalate and Bel, 2017). For example, around 42% of the main social benefits come from time savings, and most of the deviation traffic was from conventional trains for Madrid-Barcelona corridor (1998), Madrid-Seville (1987), Madrid-East Coast (2003) and Madrid-North (2002) (Albalate and Bel, 2017).

A second key benefit of HSR is safety. Although there have been some HSR accidents, and only few of them reported fatalities; HSR is the safest transportation mode of passenger fatalities per billion passenger-kilometres (Rutzen and Walton, 2011). Japan is the clear leader with no fatalities since the HSR services began in 1964, while France also has had no fatalities except two at stations on conventional lines of TGV trains. In general, HSR is much better than road transport and compares positively with air transport in terms of safety (Amos, Bullock and Sondhi, 2010).

A third key benefit of HSR is that a greater level of comfort can be offered by HSR than other modes such as conventional rail, road or air travel. Factors affecting comfort include noise, space, acceleration, and other services that can be provided by HSR operators such as catering services, unlimited use of electronic devices, and even a nursery for children, in some cases.

Congestion and delays in road and airports can also be reduced by HSR. However, a higher capacity of transport is offered by HSR which is up to 400,000 passengers per day, and it is achieved on the Tokaido Shinkansen (Tokyo to Osaka, 515km) (Angoiti, 2010; Rutzen and Walton, 2011).

When it comes to environmental impacts, HSR is known to be a lower polluting mode, although the quantity of polluting gases used by HSR depends on the amount of electricity consumed and the pollution arising from its generation. HSR also generates social benefits mostly reducing the accident rate through attracting road passengers to HSR, which has an excellent safety record (Pourreza, 2011; Albalate and Bel, 2017). Other indirect benefits achieved with HSR are related to economic development. For example, the Shinkansen has increased the employment rate in the city of Kakogawa located 230 kilometres away from the capital Tokyo by 8% (Pourreza, 2011). Increasing capacity on the route was the main reason for constructing the major HSR lines worldwide such as the first Shinkansen and TGV lines. For example, the spare capacity was one of the main reasons for not considering HSR development in the UK in the 1970s and 1980s when other European countries such as Italy started developing their HSR lines (Givoni, 2006). However, there is a plan towards the attraction of economic activities to the major regional cities connected through HSR while systems can help contain urban sprawl and promote a more logical territorial structure (Rutzen and Walton, 2011). The key factor in the successful development of HSR is identification of priority corridors and that has been measured in terms of passenger demand, revenue and economic development. For example, the development of the Shinkansen HSR network has existed since its operation on 1964 and that has brought benefits to the regional and national economy while the local communities might contribute a proportion of the funding (Rutzen and Walton, 2011).

On the other hand, HSR also brings some economic, social and environmental disadvantages. First, land occupation and environmental damages, as the designers always try to avoid curved tracks for HSR that can cause accidents whilst trains operate at high speed over 250 km/h. In this case, the process of constructing infrastructure for HSR will take up many different lands such as residential areas, forestland, farmland, etc. In order to operate in straight lines, HSR has a high proportion of track on structures (viaducts, bridges, embankments) and in tunnels and cuttings. This leads to problems of visual intrusion, severance and ecological disturbances, Second, the huge investment necessary to build an HSR line that is mainly due to the high maintenance costs and the low demand in many corridors, which might make it difficult to justify some investments from a socioeconomic point of view (Lusvter, 2015). Third, the high fares mean that HSR users are largely from high-income groups, leading to concerns about social exclusion. In this case, the majority of low income riders use the conventional train or road transport (Chen, Tang and Zhang, 2014).

III. METHODOLOGY

A. Literature Review

1) Operator Cost of High-Speed Rail Technology

Building an HSR infrastructure worldwide usually requires a specific design in order eliminate all technical restrictions that might limit the commercial speed, including the roadway-level crossings, and frequent sharp curves unsuitable for higher speed. In this case, the comparison between different HSR projects in terms of construction costs is difficult since the technical solutions adopted to implement these features vary widely in each case (De Rus, 2012). For the infrastructure construction costs of many HSR lines in service or under construction, the planning and land costs, and main stations are excluded, as the average cost of an HSR line per kilometres ranges from €10 to €40 million in 2009 prices (De Rus, 2012). Preston (2013) found out that the wide range of construction costs of HSR lines as shown in Table 5 and the lowest costs were being achieved in Spain and France for costs range from €7.8-20.0 million and €4.7-18.8 million respectively in 2005 prices. The low construction cost in Spain and France compared to Japan and Germany is due to the design high-speed lines in these countries for passenger trains only (Preston, 2013).

Country	Construction cost per kilometre (€ million) in 2005 prices	CPI in January 2005	CPI in January 2017	Index	Construction cost per kilometre (€ million) in 2017 prices
France	4.7-18.8	91.3	107	1.17	5.5-22.0
Germany	15.0-28.8	91.4	108.1	1.18	17.7-34.1
Japan	20.0-30.9	100.5	103.6	1.03	20.6-31.9
Spain	7.8-20.0	86.7	107.9	1.24	9.7-24.9

Table 5: Construction Costs per route km of new high-speed lines
Source: (Preston, 2013)

Moreover, lower construction costs in France and Spain are due to the construction procedures, including the existence of the less populated areas that are located outside the major urban centres and the similar geography. For example, the cost of construction an HSR line in France is minimised by adopting steeper grades rather than building viaducts and tunnels, as well as acquiring more expensive land in order to construct straighter lines and that leads to a reduction in operating and maintenance costs. In Germany and Japan, the construction costs are more expensive because of building HSR lines over more densely populated areas and involving blasting tunnels through mountains respectively (Campos, De Rus and Barron, 2006). The HSR's energy consumption is accounted of 5% lower in France than Germany because of being directly developed by the rail operator rather than included in the infrastructure same as in other countries, as well as its cheaper nuclear source (De Rus Mendoza, 2012). In Europe, experience of the infrastructure costs of building, maintaining and operating HSR for a 500 km are presented in Table 6, as the construction cost varies from case to case and it usually depends on different major contributors such as land prices, amount of tunnelling involved, and costs of entering large cities (Nash, 2010).

Category	Total costs (€ million)	Units	Cost per unit (€ thousand)
Infrastructure construction costs	6,000 - 20,000	500 km	12,000 - 40,000 per km
Infrastructure maintenance costs	32.5	500 km	65 per km
Rolling stock costs	600	40 trains	15,000 per train
Rolling stock maintenance costs	36	40 trains	900 per train
Energy costs	35.7	40 trains	892 per train
Labour costs	19.8	550 employees	36 per employee

Table 6: Estimated costs of a 500 km HSR line in Europe in 2004 prices
Source:(Nash, 2010)

In terms of the social discount rate, it is the financial return expected by investing in a project and it usually depends on the length of the project's lifespan. In Europe, the discount rate ranges between 3% and 6%, while it is generally higher in the three of the Asian developing countries (India, Pakistan, and Philippines), in the range of 12-15% (Zhuang et al., 2007). For example, the UK government indicates a discount rate of 3.0%, 2.5%, 2.0%, 1.5%, 1.0% for projects with a lifespans of 31-75 years, 76-125 years, 126-200 years, 201-300 years, 301 years and above respectively (Zhuang et al., 2007). As recommended by the European Commission, the social discount rate is 5% in real terms for the evaluation of infrastructure projects (Rus et al., 2009).

In this case, the same percentage of the social discount rate (i) of the cost of infrastructure and other facilities and equipment costs will be used in this section whilst the average construction cost per kilometre of a given HSR line (c_c) dependent on the length of the line (L). On the other hand, the operation period of time for the Riyadh-Dammam high-speed rail line and any HSR project in the world is usually estimated to start after finishing the infrastructure building (t) and the proportion of the construction costs spent on planning usually reaches up to 10% (ρ). However, the rest of the total infrastructure construction costs (90%) count for the infrastructure construction costs and superstructure costs. The unit costs of infrastructure construction and maintenance, and the acquisition, maintenance and operating of rolling stocks used in this paper are shown in Table 7.

Infrastructure	Cost value	Unit
The unit construction cost of a given HSR line	26,600,000	€/km
The unit cost of regular maintenance of a given HSR line	35,500	€/year
The unit cost of acquiring a rolling stock	45,000	€/seat
Average unit cost of operating a rolling stock	13.3	€/seat-km
The unit cost of maintaining a rolling stock	0.0124	€/seat-km

Table 7: Characteristics of the HSR costs in 2017 prices

Source: (Janic, 2017)

During one year of HSR's life cycle, construction and maintenance costs of HSR infrastructure are expressed per unit of length of the HSR line, as the unit cost of regular maintenance of a given HSR line is assumed by using the Table 27. Under assumptions on train capacity, initial demand, line length and train commercial speed, 5% of social discounting rate is considered and applied in this paper for both project infrastructure and acquiring rolling stock (Campos, De Rus and Barron, 2007a). Regarding the acquiring of rolling stock, the total number of trains needed for the HSR corridor is mainly related to the number of passengers and frequency. However, the risk of failing has a value of 1.5 that is associated to provide services versus the costs of acquiring, operating and maintaining an over-sized fleet, and it is ranged between 1.25 and 1.6 in the real world (Campos, De Rus and Barron, 2007a). However, the average unit cost of acquiring a train during a given period of time is ranged between €45,000 per seat and €50,000 per seat, as it is dependent on the number of trains and an average of €47,500 per seat is applied in this paper (Janic, 2017).

In France, the energy consumption of the South-East new line is 16.5 kWh per kilometre at a speed of 300 km/h (Levinson et al., 1997). On the other hand, the value of energy unit price is assumed €0.024 kWh-hour using the rate of electricity costs for industrial use in Saudi Arabia in 2015 prices (U.S. Commercial Service, 2015).

The costs of sales and administration are mainly dependant on the number of employees and automated ticketing machines needed for a given level of forecasted traffic demand. In this case, the costs can be assumed as 10% of the passenger revenue in Saudi Arabia, while the annual initial demand was forecast to be 13.2 million passengers. It is critical to decide which kind of pricing should be followed for the calculation of high-speed rail's fares, as the average fare is an important element of the generalised cost of travel (De Rus, 2011). In Spain, the revenue data that was published by Spanish government in 2014 is usually used by the number of passengers to compute the average price of tickets, as the price during the span of investment is kept constant for most lines and it reflects the competition between HSR and air transport (Albalate and Bel, 2017).

The average unit maintenance cost of a train during the observed period is assumed of 0.0124 €/seat-kilometre, and it is dependent on the features of trains and their seat capacity. On the other hand, the annual utilization of a train is also assumed to be 500,000 km per seat (Janic, 2017).

2) User Cost of High-Speed Rail Technology

The user time related to the journey is taken into account in order to calculate the total social cost. In transportation studies, the user travel time is broken into several components including walking (access/egress) time, waiting time, and in-vehicle time. However, the access time is normally defined as the time taken from one's door (e.g. home, work, etc.) to the first transportation infrastructure used in the city (Allard and Moura, 2013). It is the time spent by the traveller in getting to a metro, bus station, rail station, airport terminal, etc. For travelling by HSR, the access time could mean the time spent on a bus, metro, or in the car (e.g. private or taxi), in addition to walking time as shown in Table 8.

Access Mode	Access Time (min)	
	Madrid Atocha Station	Barcelona Sants Station
Car (Private or Taxi)	15	10
Local Train	15	12
Metro	30	12
Bus	45	20

Table 8: Average access time to get to HSR stations in Madrid and Barcelona by different modes
Source: (Pagliara, Vassallo and Román, 2012)

On the other hand, the egress time is defined as the time taken from the first transportation infrastructure used in the city (B) to the final destination. In this case, the main difference between access and egress time is mostly for travel to/from HSR station and the egress time was found to be 32% higher than access time, which may be due to greater familiarity at one's origin with the transportation options rather than at the destination for a long distance trip. Access/egress times can also include other access options beside car such as any transit service (e.g. bus, metro, etc.) and by walking. In some studies, the coefficient for walking time has valued as almost twice that of in-vehicle travel time. Allard and Moura (2013) indicated the amount of time required to get to/from the Lisbon Portela International Airport, the Oriente Rail Station and the Sete Rios Bus Terminal during morning rush hour, as the walking time was estimated from a walking speed of 4 km/h (1.1 m/s).

In Saudi Arabia, car travel (e.g. private or taxi) the only choice transport mode to access and egress from the HSR stations in Riyadh and Dammam, the two main cities along the corridor. According to DeNicola et al. (2016), the speed limit in the urban area is normally 45 km/h and ranges from 80 to 120 km/h on highways between cities. The locations of HSR stations in the cities of Riyadh and Dammam are assumed the same as the existing stations of conventional rail line managed by Saudi Railway Organization (SRO). However, the distances from the cities' centres and railway stations are measured by using Google Map as shown in Figure 2. According to the Google Map, there are three different ways to reach the HSR station in Riyadh by car with different distances: 15.8 km, 23.3 km, and 16.7 km. In this case, the average distance to/from can be calculated by adding these three distances and divided by 3 to get an estimated distance of 18.6 km. For Dammam City, there are also three different ways to/from the HSR station within different distances of 31.7 km, 28.6 km, and 33.1 km, as the estimated average distance is 31.1 km. In addition, the average access/egress distance is 24.9 km that can be applied in this section resulted from the average of both distances to/from the two HSR stations in Riyadh and Dammam.

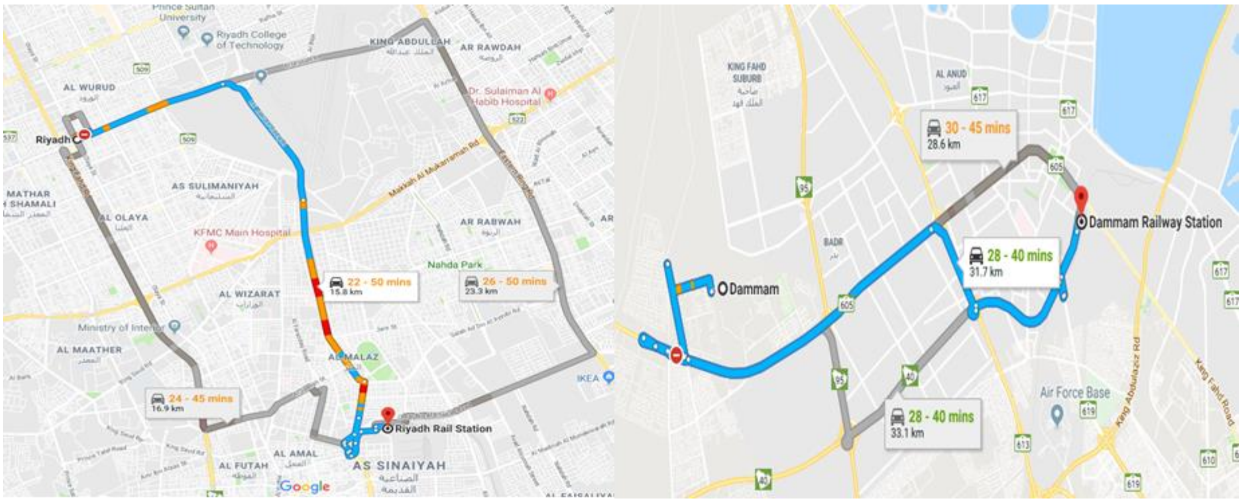

Figure 2: Driving to/from Riyadh Railway Station (Left) and to/from Dammam Railway Station (Right)

Source: Google Map

The waiting time is determined as one of the most important factors of the total user cost for all public transport modes, as it starts counting when a passenger arrives at the rail station when the passenger boards the train. However, the waiting time is a very critical element for judging the service of the passenger, as a railway passenger usually faces different types of waiting due to different reasons. For example, the waiting time might be longer if trains running behind schedule and most trains meet with some delay during rush hours. The value of time is almost expressed relative to the driving time in the case of waiting for trains, which it means passengers rate one minute of waiting as equivalent to 2.5 minutes of driving (Vansteenwegen and Vanoudheusden, 2007). The average waiting time can be estimated as a fraction of the headway, while the average of headway is calculated by dividing the length of the operating day by the service frequency (F_t) (Davies, 2011). The headway per train is equal to the half of the transport service frequency on the corridor per hour. For HSR, the check-in and waiting time is between 10 and 15 minutes (Pagliara, Vassallo and Román, 2012).

The Value of Time (VOT) is important for management and evaluation of transport investment decisions and considered as one of the key inputs related to travel demand models. It also is defined as the price that travellers as willing to pay in order to acquire an additional unit of time, while the value of time savings is the willingness to pay for time between two different transportation alternatives (Athira et al., 2016). The VOT is also counted as one of the most important outcomes that can be extracted from the experiment of stated preference, which concerning for the willingness to pay, in order to save time. The value of time for personal journeys varies usually by circumstances, which ranges between 20% and 90% of the gross wage rate within an average of around 50% and generally much higher for business travel. In this case, the value of walking time (access/egress) and waiting time is 1.6 to 2.0 times the in-vehicle time (Small, Verhoef and Lindsey, 2007). The value of time is also assumed to be €8.2/h, as it depends on many aspects such as trip purpose, socioeconomic and demographic characteristics, the total duration of the trip, etc. (Levinson et al., 1997).

The values of time for private trips were estimated to be €10/h, €12/h and €6.5/h for rail, car and coach respectively, based on Stated Choice data using for the Swedish national forecasting model in price level 2008 (Borjesson, 2014). Daniels, Ellis and Stockton (1999) identified the value of time as one component in the total equation of user cost and it can be calculated by multiplying an hourly wage rate by an average ridership component. For business journeys, the value of time depends on the cost saving, which considers the benefit of time saving in terms of cost savings to the employer (Batley, Mackie and Wardman, 2013). However, the value of time savings may be more valuable on longer distance trips, as it is noted and recommended in the Netherlands and Sweden. On the other hand, lower value of time can be applied to time savings on shorter distance trips, as the value of time for employee in time savings requires an appropriate valuation of leisure time (Batley, Mackie and Wardman, 2013). Small, Verhoef and Lindsey (2007) defined the value of time as a fraction of the wage rate. For example, the value of time is equal to **1.33** of the wage rate per hour for work trips and business in terms of cost to employer whilst it values of one-third for shorter commuting (less than one hour round trips) and **two-third** for longer trips (Gwilliam, 1997; Small, Verhoef and Lindsey, 2007).

However, the weighting perception of walking time is mainly dependant on the easiness to find the direction, and the easiness of walking control of flow, while comfort, safety, security, type of trips, and amount of time to wait is the main factors of weighting perception of waiting time. In this case, the values of weighting perception for access/egress and waiting times are worth **two** and **three** times in-vehicle time respectively and will be used in this model (Wardman, 2004).

3) External Environmental Cost of High-Speed Rail Technology

Maout and Kato (2016) defined the external costs as the costs generated by transport users but paid by surroundings, the environment, people, and the society as a whole, including air pollution, noise, accidents and climate change. The external costs associated with society and the transport user cannot be considered without policy intervention, as they usually refer to the difference between internal costs and social costs. In this case, the internal costs directly accepted by the transport user, such as energy cost of the vehicle, transport fares and taxes, wear and tear, and own time costs (Maibach et al., 2008). However, the external costs of transport modes strongly depend on parameters such as location (e.g. urban), peak/off-peak time, and vehicle characteristics (Maibach et al., 2008).

All of the transport modes emit significant quantities of air pollutants with different percentages, as this category harms human health, reduces visibility, damaged materials, and stresses forests and crops (Igor and Howaida, 2014). On the other hand, the most effect of air pollution on human health is due to the particulate matter such as PM_{10}, $PM_{2.5}$, Ozone (O_3), and other air pollutants. On buildings and materials damages, there are mainly two air pollutants effects. Soiling of building surfaces through dust and particles, and the degradation due to acid air pollutants mainly through corrosive processes, including NO_x and SO_2 (Maibach et al., 2008). The HSR trains are mainly depend on the primary fuel used to generate the electricity such as coal, oil and gas, and it is more complex to make comparison about air pollution emissions by HSR due to the high potentially diversity of primary using energy sources in each country (Campos, De Rus and Barron, 2007b). In the rail transport, the main key cost drivers are vehicle speed, the load factors, fuel type, geographical location of power plants, etc. (Maibach et al., 2008).The marginal cost from air pollution of HSR is 0.368 €/1,000 pkm (Albalate and Bel, 2017). Meanwhile, a value of energy consumption of 567 kJ/passenger-kilometre was reported for a load factor of 50% for the Japanese Shinkansen, a 440 kJ/passenger-kilometre for the French TGV, and a 1,702 kJ/passenger-kilometre for the TVE (Wayson and Bowlby, 1989). The electromagnetic radiation and catenary arcing problems have been considered from HSR electric operation, as an environmental hazard to induce high voltage near the wayside on electrical components that causes a potential hazard, to cause radio frequency interference, and certain health problems (Wayson and Bowlby, 1989).

The noise generated by HSR depends on each country's specific technology and track characteristics, and the generating level by the source such as the moving HS train and the distance (Janic, 2017). Other features of noise generated by HSR can be categorised in pantograph noise, wheel and rail noise, and aerodynamic noise. However, the noise usually relates to the speed of the train passing, as the faster speed can generate the higher noise (Pourreza, 2011). For example, the aerodynamic noise is a type of direct airborne noise as shown in Figure 3, which is generally generated from airflow around the body of train and the pantograph and wheel area, which is prevalent at the highest speed over 300 km/h (Temple-ERM, 2013).

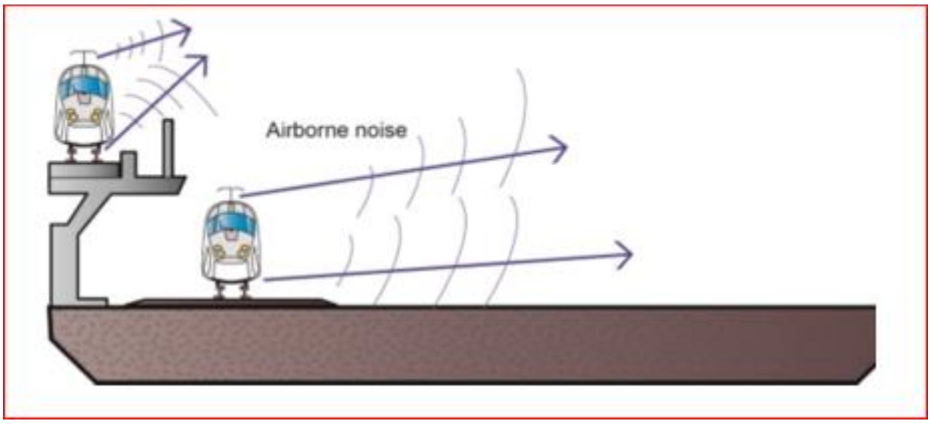

Figure 3: Direct environmental airborne noise from HSR
Source: (Temple-ERM, 2013)

In contrast to airborne noise, the ground-borne vibration generated by trains can have a major environmental impact on neighbours located nearby of a train corridor, and it includes feelable movement of the building floor, shaking of items on shelves, ratting of windows, etc.(Hunt and Hussein, 2007). In this case, the wheel-axle pressure onto the track is considered as one of the main mechanisms of the ground-borne vibration, as well as the dynamically induced forces of carriage and wheels-axle vibrations due to roughness of rails and wheels, and the effects of joints in unwelded rails (Krylov, 2017). The response caused by the train movement on locations along the line is commonly dependent on type of vehicle, the quality of the rail track, and type of foundations (Monteiro, 2009).

In this case, noise costs contain two categories of costs, which are the costs of health and annoyance. First, transport noise can cause health damages, including hearing damage at the level of noise above 85 dB(A) and nervous stress reactions such as change of heartbeat frequency, hormonal changes and the increase of blood pressure. Second, the annoyance costs that are caused by transport noise and result in economic and social costs such as discomfort, limitations on the enjoyment of desired leisure activities (Maibach et al., 2008). The HSR noise will be measured in dB(A) scale (decibels), as the values of noise levels that have been made, ranging from 80 to 90 dB(A) (Campos, De Rus and Barron, 2007b). The noise on-board HS trains is an important element of internal comfort, as trains operating at high speeds usually generate noise that consists of rolling, aerodynamic, propulsion and equipment sound.

Moreover, the main component in the noise pollutions of electric trains is the rolling surface of the steel wheel on the steel track, as these pollutions mainly dependent on the type of track, train speed, surface conditions of both rail and wheel. However, the type of brakes, the presence of noise wall, and the length of the train are the main cost drivers, as there is a significant impact of the type of brake on the noise costs. (Maibach et al., 2008). This noise generally can affect three groups of land use activities: land with residence buildings, quiet land with planned outdoor use and land with daytime activities such as schools, businesses, libraries, etc. It is usually necessary to take into account to avoid noise to the population located close to railway lines by providing the noise-mitigating barriers and that will help in absorbing the maximum noise levels by around 20 dB(A) for using single barrier and 25 dB(A) for the double barrier (Janic, 2017). In this case, the noise levels are a major concern in high-speed rail that needs to reduce its emissions. For example, the noise level for the French TGV is reported as a 97 dB(A) at 25 m from the track and a speed of 272 km/h and a 93 dB(A) for the German ICE at speed of 300 km/h (Profillidis, 2014).

Levinson, Kanafani and Gillen (1999) evaluated the full cost of three intercity transport modes, including air, road, and HSR in order to compare the economic suggestions of investment for the for the California corridor, linking Los Angeles with San Francisco. In addition, HSR produces less noise pollution for a given transport task than other existing transport modes, while the noise external cost of HSR was estimated €0.01803 /1,000 pkm (Hume Regional Development, 2014).

The external accident cost is mainly related to traffic accidents and dependent on the accident level and the insurance system. However, there are many categories of the accident cost such as the costs of medical and administrative, damage of materials, and the production losses. In addition, the most impacts of accidents in rail transport are weather condition, traffic volume, and level of separation between transport systems, especially between different types of trains (Maibach et al., 2008). The high-speed rail system is mainly designed to reduce the possibility of accidents, as it is the safest form of transportation in the world proven by decades of safe operations. In this case, the Japanese Shinkansen have been known as safest HS services worldwide since the first line opened in 1964 with free of accidents, passenger and staff fatalities and injuries due to collisions and derailment of trains. The only fatal accidents with deaths and injuries of passengers and staff have happened at the HSR systems in Spain, Germany and China as shown in Table 9.

Country	Number of trains	Passengers on board	Year	Cause	Fatalities	Injuries
Spain	1	222	2013	Extreme speed on bend	79	139
Germany	1	287	1998	Wheel breakup	101	88
China	2	1630	2011	Railway signal failure	40	210

Table 9: The main characteristics of the fatal HSR accidents
Source: (Janic, 2017)

In Saudi Arabia, a train was collided by a stray camel forty kilometres away from Qassim station in 2017 as shown in Figure 4, causing no injuries in passengers (Gulf Daily News, 2017).

Figure 4: A passenger train collided with a stray camel on Riyadh-Qassim corridor
Source: (Gulf Daily News, 2017)

The average of external accident costs are usually calculated based on UIC accident statistics up to date, which range between €0.08/train-km and €0.30/train-km in European countries in 2007 prices (Maibach et al., 2008). The average for the Australian proposed HSR line connecting Melbourne to Canberra, the accident costs is estimated to be €1.23 per 1,000 passenger kilometre by 2036 compared to the total cost of passenger vehicle accidents in Australia, which was estimated between €14.09 billion (2009) and €22.95 billion (2011) (Edwards, 2012). The impacts of climate change of transport are mainly caused by emissions of the greenhouse gases such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) (Maibach et al., 2008). However, all transport modes, including HSR emit pollutants that can affect global climate, and induced by worldwide Greenhouse GAS (GHG) emissions, which is counted as one of the key topics of global research output. (Albalate and Bel, 2017). In this case, the energy use impacts are mainly dependent on average temperature, especially for summer air conditioning (Maibach et al., 2008).

In terms of the energy consumption and emissions, Table 10 shows the emission intensity based on years 2000, 2001, and 2002 for the Madrid-Seville HSR corridor.

Year	2000	2001	2002
Traffic (million pkm)	1,924	2,077	2,181
Energy consumption (GJ)	519,572	571,176	576,852
Greenhouse gases emission (t CO_2 eq)	75,722	74,134	89,534
Energy Intensity (GJ per 1000 pkm)	0.27	0.28	0.26
Emission Intensity (k CO2 eq. per 1000 vkm)	39	36	41

Table 10: Energy and emission of the Madrid-Seville corridor
Source: (Pérez-Martínez and López-Suárez, 2005)

The emission of GHGs is planned to decrease in Europe to an average of 5.9 gCO_2/s-km, 1.5 gCO_2/s-km, and 0.9 gCO_2/s-km by the years of 2025, 2040, and 2055 respectively (Janić, 2016). Meanwhile, the increasing in temperature is an apart of climate change, which is considered as a threat to the rail network, and the risk of failures due to track expansion increases. Due to climate change, the expected increases in temperature are challenging the ability of rail operators to maintain current operating practices and avoid any delays due to increasing temperature during summer (Chinowsky et al., 2017). In Saudi Arabia, a conventional train derailed after flooding from heavy rains on February 2017 near the eastern city of Dammam city that caused the rail to drift and carriages were separated from each other as shown in Figure 5, while one train car overturned (Arabnews, 2017a).

Figure 5: Railway track inundated by water (left) and a train derailment near Dammam (right)
Source:(Arabnews, 2017a)

The marginal cost of climate change of HSR is equal to €0.824/1,000 pkm and used in this section (Albalate and Bel, 2017). As a result , the cost calculation of external environment uses the vehicle-kilometre and the unit environmental cost used in previous environmental cost studies, which can measure the external costs due to the operating performance of the transport technology (Li, 2015).

B. Spreadsheet Cost Model

In this paper, the methodology is to determine the estimated total social costs of a new HSR line worldwide and apply it to the case study of Saudi Arabia for the Riyadh and Dammam corridor, using a Spreadsheet Cost Model mainly based on Microsoft Excel. However, estimating the total annual volume of passenger demand for the proposed HSR corridor is acquired, which it is mainly based on the results of the gravity demand model. In addition, the demand model is used as a function of independent variables for the cities alongside with the proposed line such as the population, GDP per capita, the generalized journey time, unemployment rate, years since opening the corridor, and the dummy variable. With regard to the total social costs, there are three categories included such as the operator costs, user costs, and the external environmental costs. The operator cost (OC) can be divided into the infrastructure costs, and the rolling stock costs. First, the infrastructure cost (IC) is mainly based on the construction costs and maintenance costs, which can be expressed in equation 1.

$$\mathbf{(IC) = L}\ \left\{\left[\frac{\mathbf{c_c(1+\rho)*i(1+i)^n}}{\mathbf{(1+i)^n-1}}\right] + \mathbf{c_m}\right\} \qquad (1)$$

where:

$\mathbf{L}$ = The length of a given HSR line (kilometres)

$\mathbf{c_c}$ = The unit construction cost of a given HSR (€/kilometre)

$\boldsymbol{\rho}$ = The proportion of the construction costs spent on planning (percentage)

$\mathbf{P}$ = The present value of costs of the HSR line (€)

$\mathbf{A}$ = The annual value costs (€/year)

$\mathbf{i}$ = The interest rate (%/year)

$\mathbf{n}$ = The life span of infrastructure element (year)

$\mathbf{c_m}$ = The unit cost of regular maintenance of a given HSR (€/kilometre)

In this case, the infrastructure construction cost is dependent on the percentage of the planning cost that is taken into account as a part of the infrastructure construction and the length of the corridor. In addition, the operator cost of the HSR infrastructure construction cost is given by the annual value, using the capital recovery factor (Rogers and Duffy, 2012).

Second, the rolling stock cost is divided into three categories: acquisition (RSC_A), operation (RSC_O), and maintenance (RSC_M) of the rolling stocks needed to run the services for the proposed route, as they are expressed in equation 2.

$$\mathbf{RSC}= \bar{\mathbf{q}}\left\{\left[\frac{C_t * c_A * i(1+i)^n}{(1+i)^n-1}\right] + (2 * c_O * F_t * L) + (c_M * u_t * C_t)\right\} \qquad (2)$$

where:

$\bar{\mathbf{q}}$ = The average seat capacity of a rolling stock (seat)

$\mathbf{C_t}$ = The number of rolling stocks acquired in the t-th year of the observed period (trains)

$\mathbf{c_A}$ = The unit cost of acquiring a rolling stock (€/seat)

$\mathbf{c_O}$ = Average unit cost of operating a rolling stock (€/seat-km)

$\mathbf{F_t}$ = The transport service frequency on the corridor during time (train/hour)

$\mathbf{c_M}$ = The unit cost of maintaining rolling stock (€/seat-km)

$\mathbf{u_t}$ = The average utilization of a rolling stock in the t-th year of the observed period (km/seat)

In this case, the acquisition cost is given by the annual value that is calculated by multiplying the number of trains by their average capacity, and the average unit cost of acquiring rolling stock per seat as presented in equation 2. The number total number of acquired trains (RS_t) is determined by the multiplication of the estimated number of passengers and frequency as shown in equation 3.

$$\mathbf{RS_t} = (\mathbf{1.5}) \times \boldsymbol{\tau}\frac{\mathbf{Q_t}}{\mathbf{O_d} \times \mathbf{Q_e}} \qquad (3)$$

where:

$\boldsymbol{\tau}$ = The operation cycle time of the train (hour/train)

$\mathbf{Q_t}$ = The projections of the (one-way) daily demand (passenger)

$\mathbf{O_d}$ = Operating daily hours (hour)

$\mathbf{Q_e}$ = The effective occupation (seats)

The daily number of passengers demand (Q_t) can be determined by the division of the initial annual demand by the number of direction that is normally has a value of 2, while the effective occupation of capacity and the operating daily hours are determined of 75% and 18 hours, respectively.

The operation cycle time of the train along the corridor (τ) is estimated by adding the average turnaround time of a train at the begin and end stations, and the operating time in a single direction as shown in equation 4.

$$\boldsymbol{\tau} = \mathbf{2} * (\mathbf{L}/\mathbf{v}) + (\mathbf{20} + \mathbf{20})/\mathbf{60min} \qquad (4)$$

The user cost is mainly defined as the door-to-door travel costs and broken into three components including access/egress time, waiting time, and in-vehicle travel time. In this case, the access time is the time spent by the traveller from the origin point (e.g. home, school, shop, etc.) to the HSR station, while the egress time is known as the time spent to get to their final destination from the HSR station. On the other hand, the waiting time is determined as one of the most components of the user time and it is counted from the time that a passenger arrives at the HSR station until the train leaves. The in-vehicle time is mainly dependent on the length of the corridor and the operating speed of the train. As a result, the user travel time (UT) is calculated as shown in equation 5.

$$\mathbf{UT} = \frac{\mathbf{D_{AE}}}{\mathbf{V_{AE}}} + (\frac{\mathbf{1}}{\mathbf{2}} * \mathbf{Headway}) + \frac{\mathbf{L}}{\mathbf{v}} \qquad (5)$$

where:

$\mathbf{D_{AE}}$ = The average access/egress distance to/from the HSR station (kilometre)

$\mathbf{V_{AE}}$ = Average travel speed (kilometre/hour)

L= The average length of a given HSR line (kilometres)

v = The average operating speed (km/h)

In order to calculate the total annual user time, the annual number of passenger demand per direction is needed for both access/egress and in-vehicle components, while total annual number of passenger in the time period is required. In this case, the total annual passenger time is expressed in equation 6.

$$\mathbf{UTT} = (\mathbf{2} * \mathbf{Q_t} * \mathbf{T_{AE}}) + (\mathbf{Q} * \mathbf{T_{WT}}) + (\mathbf{Q_t} * \mathbf{T_{IV}}) \qquad (6)$$

where:

$\mathbf{T_{AE}}$ = The average access/egress time per passenger (hour)

$\mathbf{Q_t}$ = Passenger demand in the time period t per direction (passenger / year)

Q = Passenger demand in the time period t (passenger / year)

$\mathbf{T_{WT}}$ = The average waiting time per passenger (hour)

$\mathbf{T_{IV}}$ = The average in-vehicle time per passenger (hour)

It is commonly known that the total user cost is mainly related to the generalised travel time including the access/egress time, waiting time, and the in-vehicle time. However, this value needs to convert to generalised travel cost by multiplying each component by the weighting perception factor and the value of time as presented in equation 7.

$$\mathbf{TUC} = [(\mathbf{w_{AE}} \times \mathbf{TT_{AE}}) + (\mathbf{w_{wt}} \times \mathbf{TT_{WT}}) + \mathbf{TT_{IV}}] \times \mathbf{VOT} \qquad (7)$$

where:

TUC = The annual total user costs (€/year)

$\mathbf{w_{AE}}$ = The factor to represent the weighting perception of access/egress time vs. in-vehicle time (number)

$\mathbf{w_{wt}}$ = The factor to represent the weighting perception of waiting time vs. in-vehicle time (number)

VOT = Value of in-vehicle time for HSR (€/hour)

With regarding the value of time, the average hourly wage rate is required which is mainly based on the division of average monthly wage rate and the working hours per month.

Finally, the external environmental costs can be calculated by multiplying the unit costs of different components such as air and noise pollution, accident and climate change by the total passengers-kilometres and expressed in equation 8.

$$\mathbf{TEC} = (\mathbf{UAP_c} + \mathbf{UNP_c} + \mathbf{UA_c} + \mathbf{UCC_c})\ \mathbf{X\ PKM} \qquad (8)$$

where:

$\mathbf{UAP_c}$= Unit air pollution costs per passenger-kilometre (€/pkm)

$\mathbf{UNP_c}$= Unit noise pollution costs per passenger-kilometre (€/pkm)

$\mathbf{UA_c}=$ Unit accident costs per passenger-kilometre (€/pkm)

$\mathbf{UCC_c}=$ Unit climate change costs per passenger-kilometre (€/pkm)

PKM= Total Passenger per kilometres

In this case, the Purchasing Power Parity (PPP) rate of different countries is necessary needed to determine the unit cost for the external costs per vehicle – kilometre, which is mainly based on the values of currency rates.

C. Results and Discussion

The forecasting of travel demand is needed in order to estimate the total social costs of proposed HSR lines worldwide. However, the gravity regression model was used to calculate the expected demand for the first year of an HSR operation (2040) for the proposed Riyadh-Dammam corridor to serve two large cities in Saudi Arabia within a length of 412 kilometres. In this case, the forecasting travel demand was estimated from 13,205,212 trips in the first year, based on different parameters including population, GDP per capita, generalized journey time, unemployment rate, years since opening, and country specific dummy variables.

The results of total social costs of constructing and operating an HSR line worldwide are divided into three categories:

First, the total operator costs which include the infrastructure construction and maintenance costs, rolling stock acquisition, and operating and maintenance costs. In this case, the main different parameters included in the calculation are the length of corridor (L) of 412 kilometres, the estimated project timeline (n) of 35 years, the capacity of train (c) of 417 seats, the capacity load factor (l) of 75%, the average commercial speed (s) of 300 km/h, and the 18 daily operating hours (06:00-24:00).

The infrastructure cost is mainly based on both construction and maintenance costs of the HSR line. In this case, the infrastructure construction cost of **€736,226,759 per year** results from the multiplication of the capital recovery factor, length of the line, the annual infrastructure construction unit cost of €26,600,000 per km, and the estimated proportion cost on planning (ρ) of 10%. The capital recovery factor is resulted of 6%, as it is dependent on the estimated project timeline and the social discount rate (i) of 5%.

On the other hand, the infrastructure maintenance cost is **€14,626,000 per year**, which was calculated through the multiplication of length of the corridor and the infrastructure maintenance unit cost of €35,500 per year.

As a result, the total infrastructure construction and maintenance costs are presented in Table 11 for a value of **€750,852,759 per year.**

Item	Value
Length of line	412
Construction unit cost (€/km)	26,600,000
Proportion cost on planning (%)	10
Maintenance unit cost (€/year)	35,500
Construction period (year)	5
Cycle time (year)	35
The social distant rate (i) (%)	5.0
Infrastructure Construction Cost (€)	**12,055,120,000**
uniform series present worth factor	27.07559458
Capital recovery factor (%)	0.06
Infrastructure construction cost (€/year)	**736,226,759**
Infrastructure maintenance cost (€/year)	**14,626,000**
Total infrastructure construction and maintenance costs (€/year)	**750,852,759**

Table 31: The total infrastructure construction and maintenance costs (€/year)

The effective occupation is mainly based on the estimated load factor of 75% and the rain capacity of 417 seats to get a result of **313 seats**. In addition, the total projection of on-way daily demand is 18,089 passengers that is mainly dependent on the initial annual demand of 13,205,212 that was determined through the output of gravity model and the number of direction.

The number of services (trains) is resulted of **58 daily trains** as shown in Table 12, which is mainly based on the daily projection demand and the effective occupation. On the other hand, the service frequency is calculated of **3.21 ≈ 4 trains per hour**, which is based on the number of daily passengers per direction, the effective occupation, and the daily operating hours. In addition, there is a train running every **20 minutes** by dividing 60 minutes by the service frequency, which will increase with the growing of demand and might reach a reasonable value of one train every 15 minutes or less.

Item	Value
Days per year (day)	365
Round trip (direction)	2
Operating hours per day (hour)	18
Load factor (%)	75
Train capacity (seat)	417
Effective occupation (seat)	313
Annual demand initial (passenger/year)	13,205,212
Per day, Initial Year (t=5)	18,089
Number of service per day-direction	58
Service frequency per hour	**3.21 ≈ 4**

Table 42: The service frequency per hour

The number of trains acquired for the proposed corridor was resulted of **21 trains**, which is mainly based on the train operation cycle time of 3.41hour/train, the value to the risk of failing of 1.5, and the service frequency mentioned previously. Based on multiplication of the number of trains needed of 21 trains, the average seat capacity of train of 417 seats, and the unit cost of acquiring a rolling stock of €47,500 per seat, the acquisition costs of rolling stock resulted of **€25,403,235 per year** as shown in Table 13. In addition, the value was converted to an annual value by multiplying it by the value of capital recovery factor of 0.06 resulted from equation 1.

Item	Value
Train capacity (seats)	417
Number of acquired trains (trains)	21
Unit cost of acquiring a train (€)	47,500
Rolling Stock Acquisition Cost (€/year)	**25,403,235**

Table 53: The rolling stock acquisition Cost (€/year)

The operating costs of rolling stock resulted of **€29,247,913 per year** as shown in Table 14, which is mainly based on the average unit cost of operating a rolling stock of €13.3 per seat-kilometre, the length of the corridor of 412 kilometres, the train capacity, and the transport service frequency.

Item	Value
Average unit cost of operating a rolling stock	13.3
The transport service frequency on the corridor during time	4.00
Train capacity	417
Length of line	412
Rolling stock operating cost (€/year)	**29,247,913**

Table 64: The rolling stock operating cost (€/year)

A multiplication of the unit cost of maintaining a rolling stock of €0.0124 per seat-kilometre, the number of acquired trains, train capacity, and the annual utilization of 500,000 kilometres-seat is needed to achieve a value of **€54,293,300 per year** for the rolling stock maintenance cost as shown in Table 15.

Item	Value
Unit cost of maintaining a rolling stock	0.0124
Number of acquired trains	**21**
Train capacity	417
Average utilization of a train	500,000
Rolling Stock maintenance cost (€/year)	**54,293,400**

Table 75: The rolling stock maintenance cost (€/year)

The total operator cost is resulted of **€859,797,307 per year** as shown in Table 16, which is mainly based on the total infrastructure and rolling stock costs of €750,852,759 per year and €108,944,548 per year, respectively.

Item	Value
Infrastructure construction cost	736,226,759
Infrastructure maintenance cost	14,626,000
Total Infrastructure Costs	**750,852,759**
Rolling Stock Acquisition Cost	25,403,235
Rolling stock operating cost	29,247,913
Rolling Stock maintenance cost	54,293,400
Total Rolling Stock Costs	**108,944,548**
Total Operator Costs (€/year)	**859,797,307**

Table 86: The total operator costs (€/year)

Second, the total user cost of proposed HSR line includes the access/egress time, waiting time, and in-vehicle travel time from the origin to destination.

The average access and egress times are mainly based on the average travel distances to/from rail stations of 24.9 kilometres and the average travel speed of 45 km/h, and resulted of 0.55 hour per passenger. In this case, the annual total access and egress times is **7,297,102 hours** as shown in Table 17, resulted from the multiplication of the factor of 2 represents both directions to/from the HSR station, the annual number of passengers per direction and the average access and egress time per passenger.

Station	Riyadh	Dammam
First distance	15.8	31.7
Second distance	23.3	28.6
Third distance	16.7	33.1
The average access/egress distance to/from the HSR station (kilometre)	18.6	31.1
Average distance for both stations (km)	24.9	
Average travel speed (km/h)	45	
Average Access/Egress Time	0.55	
Factor represents both directions Factor represents both directions to and from the HSR station	2	
The annualisation factor (days/year)	365	
Passenger demand in the time period t (passenger / year)	6,602,606	
The total annual passenger access/egress time (hours)	**7,297,102**	

Table 97: The total annual passenger access/egress time (hours)

The average passenger waiting time is 0.06 hour resulted from the half of headway, as the headway is mainly equal to half of the service frequency on the corridor during time of about 4 trains per hour. In this case, the total annual passenger's waiting time is **412,663 hours** as shown in Table 18**,** resulting from the multiplication of the average waiting time per passenger and the annual projection demand per direction of 6,602,606 passengers.

Item	Value
The annualisation factor (days/year)	365
Operating hours per day	18
The projections of the (one-way) daily demand (passenger)	18089
Passenger demand in the time period t (passenger / hour)	1004.962861
The transport service frequency on the corridor during time (train/hour)	4.00
Headway per train(hour)	0.13
Average waiting time (hour)	0.06
The projection of the yearly demand (passenger/direction)	6,602,606
The total annual passenger's waiting time (hours)	**412,663**

Table 108: The total annual passenger's waiting time (hours)

The average in-vehicle travel time is 1.37 hours and it is mainly resulted from the dividing of the length of corridor by the average operating speed. In this case, the total annual passenger in-vehicle travel time is **9,067,579 hours** as shown in Table 19, resulting from the multiplication of the average in-vehicle time and the annual projection demand per direction.

Item	Value
Length of HSR corridor (kilometre)	412
Average operating speed (km/h)	300
The annualisation factor (days/year)	365
The projection of the yearly demand (passenger/direction)	6,602,606
Average In-vehicle time (hour)	1.37
The total annual passenger's in-vehicle time (hours)	**9,067,579**

Table 119: The total annual passenger's in-vehicle time (hours)

The average value of time is necessary required in order to calculate the annual total user costs. First, the average hourly wage rate is €8.72 per hour resulted from the dividing of the average monthly wage rate of €1,395 by the working hours per week 160 hours. In this case, the value of time for business and commuting travellers are resulted of €11.6/hour and €5.82/hour respectively from the multiplication of the average hourly rate and the coefficients (1.33 and 0.667) shown in the literature review of value of time. As a result, the value of time in this paper is **€8.71/hour** resulted from the average of values of time for business and commuting travellers as shown in Table 20.

Item	Value
Average monthly wage rate (€)	1,395
Working hours per week (hr)	40
Working hours per month (hr)	160
Average hourly wage rate (€/hr)	8.72
Value of time for business travellers (€/hr)	11.60
Value of time for commuting travellers (€/hr)	5.82
Weighting perception of access/egress time	2
Weighting perception of waiting time	3
Value of time for business travellers (€/hr)	11.60
Value of time for commuting travellers (€/hr)	5.82
Average of value of time (€/hr)	**8.71**

Table 20: The average of value of time (€/hr)

The total user cost is **€216,769,247 per year** as shown in Table 21, resulting from the sum of total annual passenger access/egress time, waiting time, and in-vehicle time. In addition, the weighting perceptions of 2 and 3 that were presented in the literature review of value of time for access/egress time and waiting time, respectively are used, and multiplying them by the value of time.

Item	Value
The total annual passenger access/egress time (h)	7,297,102
The total annual passenger's waiting time (h)	412,663
The total annual passenger's in-vehicle time (h)	9,067,579
The total annual passenger access/egress time (€/year)	**127,052,357**
The total annual passenger's waiting time ((€/year)	**10,777,523**
The total annual passenger's in-vehicle time ((€/year)	**78,939,367**
Total User Costs (€/year)	**216,769,247**

Table 212: The total user Costs (€/year)

Third, the total external environmental costs of proposed HSR line include air pollution, noise pollution, accident and climate change. In this case, the conversion of Purchasing Power Parity (PPP) rates from $ to €, which was based on 2016 prices between UK and Saudi Arabia. In addition, the total passenger-kilometre was calculated of multiplying the forecasting travel demand of 13,205,212 by the length of corridor (412 kilometres).

The average air pollution cost was calculated of **€1,954,034 per year** resulted from the multiplication of the unit air pollution cost of €0.359 per vehicle-kilometre and the total annual demand of 5,440,547, 344 passenger-kilometre.

On the other hand, the result of noise pollution was calculated of **€95,758 per year** and it is mainly based on the unit noise pollution cost of €0.018 per vehicle-kilometre and the total passenger –kilometre of 5,440,547.

In addition, the average external accident cost was calculated of **€7,115,231 per year** and that was resulted from the multiplication of the unit accident cost of €1.31 per vehicle-kilometre and the total of 5,440,547 passenger –kilometre.

The average external climate change cost was calculated of **€4,375,336 per year**, which was resulted from the multiplication of the unit climate change cost of €0.82 per vehicle-kilometre and the total passenger –kilometre of 5,440,547.

Item	Value
Unit air pollution costs per vehicle-kilometre (UK)	0.368
Unit air pollution costs per vehicle-kilometre (Saudi Arabia)	0.35916
Total passenger per kilometre	5,440,547
Average air pollution cost (€/year)	**1,954,034**
Unit noise costs per vehicle-kilometre (UK)	0.01803
Unit noise costs per vehicle-kilometre (Saudi Arabia)	0.01760
Total passenger per kilometre	5,440,547
Average noise pollution cost (€/year)	**95,758**
Unit accident costs per vehicle-kilometre (UK)	1.34
Unit accident costs per vehicle-kilometre (Saudi Arabia)	1.30782
Total passenger per kilometre	5,440,547
Average accident cost (€/year)	**7,115,231**
Unit climate change costs per vehicle-kilometre (UK)	0.824
Unit climate change costs per vehicle-kilometre (Saudi Arabia)	0.80421
Total passenger per kilometre	5,440,547
Average climate change cost (€/year)	**4,375,336**
Total External costs (€/year)	**13,540,359**

Table 22: The total external costs (€/year)

As a result, the total external environmental cost is **€13,540,359 per year** as shown in Table 22, resulting from the sum of average costs of air pollution, noise pollution, accident, and climate change that was based on the values of unit costs presented in the section of external environmental cost of HSR technology.

IV. CONCLUSION

In conclusion, connecting these two large cities by an HSR system will bring new competition into the intercity market in Saudi Arabia. However, the total infrastructure construction cost for the proposed HSR line worldwide is likely to be the most important cost category, followed by the rolling stock operating and maintaining costs. In this paper, the calculation of the cost categories is mainly based on the unit costs of infrastructure and rolling stock used in Table 7 mentioned in the literature review. However, 86% of the total operator costs of the proposed HSR line result from the infrastructure construction cost. In addition, the rest of the cost values are the result of the rolling stock maintenance cost, rolling stock acquisition cost, rolling stock operating cost, and the infrastructure maintenance costs of 6%, 3%, 3%, and 2%, respectively.

In terms of the total user costs, 59% resulted from total annual passenger access/egress costs, followed by the total annual passenger in-vehicle and waiting costs within 36% and 5%, respectively. For the total external environmental costs, 53% of the cost was due to the average accident cost, following by 32%, 14%, and 1% that were the result of the average climate change cost, average air pollution cost, and average noise pollution cost, respectively. As a result, the total social costs of constructing and operating a high-Speed rail line between Riyadh and Dammam, two large cities in Saudi Arabia, is €1,090,106,913 per year, resulting from the total operator cost, user cost, and the environmental cost with values of €859,797,307 per year, €216,769,247 per year, and €13,540,359 per year, respectively. In terms of limitations, the cost data was based on the Janic (2017)'s paper on averaged rather than the most efficient. In this case, data envelopment analysis and stochastic frontier analysis would be needed to do the latter. This data may be inconsistent with the Saudi Arabian data for the Haramain High-Speed line construction costs, as well as with the data of other presented such as Campos, De Rus and Barron (2007b)'s paper. Moreover, the user costs were based on engineering data rather than real data, and the forecast of users from a global HSR model may not be appropriate to Saudi Arabia.

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