**INVESTIGATION OF THE OPERATIONAL RELIABILITY OF HIGH-SPEED RAILWAY AND POSSIBLE MEASURES OF IMPROVEMENT**

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ABSTRACT

Considering the growing congestion on roads and at airports worldwide, there is a need to improve the reliability of High-Speed Rail (HSR) transport. HSR is one of the important developments in rail transportation as it can sufficiently increase mobility whilst providing speed, reliability, comfort and safety. The reliability of HSR services can sufficiently influence the economic and environmental sustainability of a railway network.

The safety rate of HSR decreases with the deterioration of punctuality of trains. The reliability of trains is one of the most attractive features of the railway system for passengers.This research investigates the main measures to improve the reliability of HSR and compares and evaluates the reliability of different HSR systems and related influencing factors. The research takes the form of an investigation and critical evaluation of key existing HSR systems in terms of their reliability. It looks at different technical innovations that improve the reliability of HSR such as implementing a preventative maintenance regime, implementing modern signalling and traffic control systems and digitalising traffic management and timetabling. The expected outcome of this research may contribute to the development of ways to increase the railway operational reliability through a combination of new technologies, and improving the staff skills.

KEYWORDS: high-speed rail, reliability, sustainability

1. INTRODUCTION

In recent years, High-Speed Rail (HSR) has had great attention as a transport mode that can help solve the problems of moving people around in the most sustainable way. The HSR offers safe, fast, comfortable and a reliable way of transportation. HSR is one of the most promising transportation technologies that is rapidly developing worldwide. In 2011 there was 15,231 km of HSR in operation around the world but by 2025 it is expected to increase to 41,997 km (Lee, 2013). It was predicted that by 2050 around 75% of the world’s population (9.5 billion) will live in cities, and 20% of the world population will be 60 years old or over. The wealth of people also increases in such a way that by 2050, 50% of the total world population will be middle class people (Arup, 2015).

With the growth of population worldwide and the growth of wealth, the demand for travel increases. People travel more frequently and over longer distances. Roads and airports have become increasingly congested. This raises environmental and external cost concerns. HSR can help to satisfy increased demand for travel and several HSR projects currently under development worldwide. It is the most environmentally friendly, energy and resources efficient and safest mass transportation mode with 10% (pass/km) of annual average growth in Europe (De Angoiti, 2007). With the increases in wealth, consumers become more demanding in terms of quality of transport services whilst the reliability of transport becomes more important. Reliability of high-speed trains involves a punctuality of departure and no delays in arriving. Passengers valued reliability next after their safety and with the growth in personal income, there will be higher expectations for reliability. Reliability, safety, comfort, and service frequency is more important for passengers than speed. Failure of railway systems leads to longer travel times and uncertainty for consumers and as disruptions of railway system occurs there is an unavoidable need to deal with them effectively. Improving the position of the railways is an important goal to move society to a more sustainable mobility. Punctuality is one of the key points that attract people to use the railways. Implementing a preventative maintenance regime, modern signaling and traffic control systems and digitalising traffic management and timetabling can sufficiently improve the reliability of HSR.

2. RELIABILITY OF HSR

There are many influences that affect the railway network performance with respect to punctuality. The increasing extreme weather events will increase the risk of disruption and damaging to the transport systems which will affect the reliability of the railway services. Failure of infrastructure or rolling stock, construction and maintenance work and trespasses on the network affect the punctuality of the railways. Although, the railway systems have some spare capacity, it was reported that 20% of Europe’s main lines, which is about 16000 kilometres of track, is classified as bottleneck (EC, 2001). Weather conditions, needs for tunnels and viaducts, level crossings, etc. may affect the reliability of HSR performance.

2.1 Comparison of different HSR in terms of punctuality

Table 1 Comparison performance of HSR in selected countries (various sources)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Name of country | Satisfaction with punctuality and reliability (2013) | HS traffic pass.km. (billion) | Punctuality ratio | “On time”  If train delay  Is no more than | Train operator company |
| Japan | n/a | 90.28 (2015) ⁷ | 98.3% (2005) ² | 0- 1min | Shinkansen |
| France | 62% (2013) ¹ | 49.976 (2015) ⁷ | 89.3% (2016) ³ | 0- 15 min | TGV |
| Germany | 53% (2013) ¹ | 24.316 (2015) ⁷ | 94.8% (2015) ⁴ | 0-15 min | DB |
| Spain | 84% (2013) ¹ | 14.129 (2015) ⁷ | 99.6% (2010) ⁵ | 0-5 min | Renfe |
| Italy | 48% (2013) ¹ | 12.794 (2015) ⁷ | 97.3% (2014) ⁶ | 0-15 min | Trenitalia SpA |
| China | n/a | 214 (2013) ¹² | 95.4% (2015) ⁸ | n/a | CRH |
| Taiwan | n/a | 8.642 (2012) ¹³ | 99.66% (2015) ⁹ | n/a | THSR |
| South Korea | 92.6% (2010) ¹¹ | 9.937 (2008) ¹⁵ | 99.8% (2009) ¹¹ | 0-5 min | KTX |
| The Netherlands | 66% (2013) ¹ | 0.915 (2008) ¹⁵ | 94.2.0% (2015) ¹º | 0-3 min | NSL South |
| United Kingdom | 81% (2013) ¹ | 1.13 (2015) ¹⁴ | 90.2% (2015) ¹¹ | 0-15 min | Eurostar Intl |

The Tokaido Shinkansen HSR in Japan is considered to be the most reliable HSR in the world. An annual average delay for Tokaido Shinkansen is 0.6 minutes/per train. This included delays caused by natural disasters, such as earthquakes. In Japan, delays are classified as such if a train arrived more than 1 minute late whilst in Europe delays are classified if trains arrive 15 minutes later than scheduled time (Denis, 2013). Shinkansen line has a very high density of trains with 14 trains per hour. Maximum density for HSR is 15 trains per hour. Reliability of high-speed trains in Japan, South Korea and Taiwan is very high mainly due to using dedicated high-speed lines, tunnels and viaducts, advanced signalling systems and excellent training of staff.

In France, new high speed lines were designed to avoid tunneling as this gives the benefit of the possibility to implement double deck trains. The big achievement of the HSR system in France is that the TGV system is compatible with the existing conventional railways. However, if high-speed trains use the sections on upgraded conventional lines it will affect the punctuality of the railway service. TGV trains use the upgraded conventional rail in the less crowded connections and for accessing major cities where construction of new high-speed line would be excessively high. Punctuality ratio in 2016 was 89.3%, (Table 1).

Germany had some problems of constructing HSR caused by topographical specific issues dominated by mountainous terrains. Germany’s railway infrastructure was upgraded instead of building new dedicated lines only for high-speed trains and it serves passenger and freight traffic. It is a multi-purpose railway network. Train delays in Germany have increased by almost a third since 2009. The reason is the huge amount of maintenance and modernization of the existing railway network. There are also many speed restrictions related to the condition of the existing railway network, and because of this there is an increased density of traffic. Delays undermine the line capacity. In 2011 only 32% of long-distance trains arrived on time as three out of four high-speed trains were delayed (Welle, 2001).

Spain’s high speed network is one of the widest in the world, but the total traffic is small in comparison to Shinkansen and TGV. The punctuality of AVE is one of the best in Europe. Implementing the punctuality commitment on the AVE trains led to an increase in market share, increase in passenger trust, and satisfaction. High-speed trains in Spain claimed 99% punctuality in 2014 (PwC, 2011). Achieving this level of punctuality for AVE was easy enough as the railway lines have low density traffic, and it has dedicated high-speed lines. To reach this level of punctuality for Germany or Sweden would be more difficult as their high-speed trains use mixed traffic lines. If Renfe high-speed trains in Spain arrive just five minute late passengers will have a full refund for that journey.

HSR in Italy is integrated with conventional lines. This increases railway network capacity, increases the effects of HSR and prevents the deterioration of the conventional services, but it affects the reliability of services. In Italy, after the year 2000 conventional railways showed decreases in passenger numbers, but the number of passengers who use the high-speed lines is steadily increasing. In 2010 high-speed railway had 25% of the total rail traffic (Pedro, 2014). The meaning of ‘on time’ for Trenitalia means that trains arrive within 0 to 15 minutes of the schedule time. It is difficult to compare punctuality of different train operators simply because punctuality is measured differently in different countries. For example, ‘on time’ for OBB train operator in Switzerland means an interval within 0 to 5 minutes of the schedule time whilst in Austria for the train operator of SBB train the term ‘on time’ means trains arrive within 0 to 3 minutes of the schedule time. Overall, the punctuality of European average passenger train is around 93% using the 5-minute punctuality (EC, 2012). In France, ‘on time’, counts if trains arrive less than 5-minute delay of the schedule time for journeys of less than 1,5 hours, less than 10-minute for journey between 1,5 and 3 hours and less than 15-minute delay for journeys beyond 3 hours (De Consommateurs, 2017). In Korea, ‘on time’ means train arrives within 5 minutes of the schedule time (Korail, 2010). The differences in what can be classified ‘on time’ make it difficult to compare performance of HSR in terms of reliability.

In China, nearly one billion people travel by HSR every year. In 2015, the HSR network in China reached more than 19,000 km, with maximum operating speeds of up to 350 km/h and has more than 4,200 high-speed trains (China.org.cn, 2017). By 2013, the HSR in China carried around 2.5 times more passengers than in Japan (Ollivier, 2015). Punctuality of high-speed trains for departure in China in 2015 was 98.8% and 95.4% punctuality for arrival at the destination (China.org.cn, 2017).

The difference of THSR (High Speed Rail in Taiwan) compared with other HSR is that THSR network is that almost 90% of the route is running either in tunnels or raised viaducts due to topographical features such as steep gradients in the terrain (Mahmoud, 2012). Some lines in Taiwan have 56 services daily. With a maximum speed of THSR up to 190 mph and with the increasing stresses on the brakes and wheels and on infrastructure, there is a need for additional requirements for maintenance to provide a high level of performance. The frequency of services, and operating distance of railway network affect the reliability of HSR service. THSR has an excellent performance with respect to punctuality and average delays per train is 0.216 min/train (2009) with a frequency of 5 trains/h. THSR has a much lower frequency than Shinkansen which has 13 trains/h (Amos, 2010). The signal and interlocking system failure is the most common reason for train delays (Jong, 2010).

KTX-High Speed Rail in South Korea was opened for service in 2004, and traffic steadily increased on average by 11% every year. More than 300 000 passengers use the railway every day (Media, 2017). There is 412 km of infrastructure and up to 92 trains run daily in each direction with designed speed of 350 km/h. KTX trains are fitted with the automatic train control system, which allows increases in capacity of existing lines, reduces energy consumption and improves the safety of railway services. This system automatically adjusts actual train speed. Trains equipped with in-cab signalling system that informs drivers about signals ahead and also informs the main control Centre about the location of trains in real time. High-speed rail in South Korea carries more than 100 000 passengers on a daily basis, KTX accounts for more than 50% of the total rail traffic (Railway-technology.com, 2017).

In the Netherlands the 2015 punctuality of HSR was 94.2% (Table 1) which represented a huge improvement from 2007 when punctuality of the railway system was 80%. It was presumed that trains arrived on the scheduled time if delays were less than 3 minutes. However, the punctuality indicator does not give information on the length of delay. Unreliability of departures is not accounted for and does not consider the travel time variation. In order to reduce the delay time there is a need to improve traffic management during delays and disruptions.

UK has 113km of HSR in operation and planned to build another 204 km by 2020. In 2014, the number of passengers reached 10.4 million (Ltd, 2015). In 2015, the number of Eurostar high-speed trains fell by 17% to 2,421, as night-time services had been suspended from June to October due to people trying to board trains illegally (Topham, 2016). Disruption and uncertainty often lead to much more discomfort for the passengers than the few minutes of delay with which they are confronted regularly. In situations when disruptions occur the lack of information leads to a lot of discomfort for commuters. Implementing the Real-Time Passenger Information systems on board trains and at railway stations may reduce discomfort for commuters. The disruption management should quickly provide a modified timetable, rolling stock circulation and crew duties. In 2015, 81% of Eurostar trains arrived within five minutes of their scheduled arrival time and that is down from 83.8% in 2014 whilst 90.2% of trains arrived within fifteen minutes of their scheduled arrival time (Eurostar, 2016). Eurostar received almost 20,000 complaints about train delays for the same period. The main measures to improve the reliability would be by improving the engineering facilities and improving the staff skills to manage better occurrences of train delays.

2.2 Correlation between punctuality and accident rate

Table 2 Rail traffic performance and number of significant accidents in selected countries in 2014

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Country | Tonne-kilometres  (in million) | Passenger-kilometres  (in million) | Total number of accidents | Total number of person killed or seriously injured in accidents |
| France | 32 217 | 89 499 | 177 | 140 |
| Germany | 112 629 | 89 120 | 388 | 302 |
| Spain | 10 821 | 25 146 | 55 | 42 |
| Italy | 20 072 | 49 957 | 131 | 113 |
| The Netherlands | 6 169 | 20 005 | 27 | 19 |
| United Kingdom | 22 143 | 64 711 | 70 | 34 |

Source: adapted from (Eurostat 2016)

According to the European Rail Agency’s report in 2013, in the EU on average every year around 2400 significant accidents are registered on railways. More than 1000 people died in these accidents and many more injured (EC, 2013b). In 2014 in the EU there was registered 2213 serious accidents on the railways. There was a total of 1 928 people who had fatal or serious injuries, i.e. up by 9.5 % in 2013. Moving rolling stock caused the majority of accidents which was 1196 and the next highest number of accidents is 638 which involved level-crossings (Eurostat, 2016).

Table 2 shows the rail traffic performance and number of significant accidents in selected countries in 2014. Germany has the highest number of accidents in EU-28 in 2014, which were 388 accidents (Table 2). The biggest amount of accidents is related to level-crossings or rolling stock. The deadliest HSR accident happened in Germany in 1998 when 101 people lost their lives and around 100 more were injured (Akkoc, 2016). It was caused by a technical fault of the rolling stock. This accident happened when the high-speed train used the section of conventional rail at a speed of 200km/h. The major reason that Germany has such a high accident rate is that Germany’s railway network is mixed-lines where all categories of trains, including high-speed trains and freight trains can use the conventional lines, and it has very intensive traffic use. There is some correlation between punctuality and accident rate and accident rate and traffic performance. For example, Shinkansen HSR in Japan has only 0.6 min delay per trip and holds an excellent no accident rate, there have been no fatal accidents since 1964 when it was first opened for service. This can be explained by special measures, such as fenced tracks, absence of level crossings, dedicated railway line and excellent trained staff. High percentages of accidents are caused by trains running late. By improving reliability of railway services, it will improve safety too.

2.3 Punctuality of HSR leads to increasing the market share

Improving the reliability of railway services will lead to higher satisfaction levels of passengers and will increase the number of passengers. Quality improvement of railway services leads to an increasing number of passengers and this will decrease the number of people travelling by road or air. Overall, it shifts the travel to more sustainable modes of transportation, which is the railway. Punctuality of railway services is one of the major attractions for passengers as roads and airports get congested and are difficult to plan for passenger travel time effectively. High rates of punctuality not only increase the capacity of rail lines and attracts more passengers but also reduces congestion on roads and airports. Consumer expectation of reliability will only increase with the increasing wealth of people.

3. MEASURES FOR IMPROVING RELIABILITY OF HSR

Implementing advanced information communication technologies will increase efficiency of railway transport by providing real-time data from thousands of sensors and systems that will monitor and analyse this data. This will increase safety, capacity and reliability of HSR.

Costs

Improving the staff skills

Digitalise traffic management and timetabling

Preventing maintenance regime

Modern signaling systems

Dedicated type of HSR

Reliability

Figure 1 Relationship between costs and type of measures for improving reliability of HSR

There are many measures that can be taking to improve reliability of HSR and the most effective of them is dedicated HSR, but this will come at a cost. Dedicated HSR is the most expensive measure to improve the reliability of HSR. Figure 1 shows some of the measures for improving the reliability of HSR.

3.1 Dedicated type of HSR

Most countries worldwide with HSR network have decided to develop new HSR lines exclusively dedicated to high-speed trains (Japan). However, some countries have mixed HSR where high-speed trains use dedicated lines and upgraded conventional tracks (France); some countries have fully mixed railway network where most of the tracks are used by all passenger and freight trains (Germany) whilst there is one more type of HSR where the high-speed track is used by high-speed trains and conventional trains equipped with a gauge-changing system (Spain). The highest punctuality ratio belongs to dedicated HSR. Deciding to use upgraded conventional network will reduce the cost of construction but will also reduce the speed of trains. Mixed high-speed rail can have capacity problems, which occur when operating trains running at speed differing by more than 50 km/h. Moreover, mixed high-speed lines are more difficult to maintain and these lines have a lower punctuality ratio. Another important feature of the high-speed network is the double or single track. Most of the high-speed network is of double track whilst the rest is of single-track sections. These parts of high-speed networks in particular can be very vulnerable to any disruption. If any disruptions appear then there would be delays in both directions with some constraints in the frequency of services and capacity of the line. In Japan, Shinkansen operates on dedicated high-speed double track where the track is used only by high-speed trains. Using dedicated track by high-speed train service is more reliable, safe and requires less maintenance. The frequency and operating distance of railway network also affect the service reliability.

3.2 Implementing a preventive maintenance regime (Intelligent diagnostic systems- proactive maintenance)

With different types of trains using a railway line, such as commuter trains, high-speed trains, freight trains, increasing the density of line, longer operating hours and actions to improve the punctuality of trains lead to an increase in the maintenance of railways. It is important that there is a transformation from reactive to proactive maintenance. More HSR systems move from short-term maintenance solution to long term that will benefit railways. Shortening the maintenance time can be an effective measure to mitigate the train delays caused by technical failures. One of these solutions is implementing the online monitoring system that identifies where, what and when there is a need to maintain. This system can monitor wheelset condition, bogie stability, rail track condition, and it is connected to the maintenance management system. The system not only monitors in real-time rolling stock and rail track condition, but also plans a spare part order and work order. Moreover, the online monitoring system gives automatic warnings if the load or speed or both exceed what is allowed for certain routes. The system raises safety and reliability of railways and reduces the cost of maintenance. The online monitoring system minimises the impact of any interruption of infrastructure or rolling stock and maximises the time of track and rolling stock availability in addition to increasing the reliability of railway systems for customers.

This condition-based monitoring system detects possible problems in the railway network. The railway network can be maintained before it becomes unsafe to use. Maintenance issues are applied before they can become operational safety issues. Data is gathered from different sensors such as signaling systems, rolling stock sensors and from existing monitoring and telemetry systems. If any of the sensors registered a deviation on a specific parameter, the system automatically sends an alarm to the Maintenance Management Information System (MMIS). The system automatically produces the necessary type of work order: or preventive maintenance, corrective maintenance or immediate repair. The implementation of (MMIS) improves the safety and reliability of a railway network and reduces the maintenance costs. MMIS is a software tool that increases the safety on railways and improves the reliability and capacity of a railway network. MMIS software combines the planning of scheduled and emergency maintenance work, stock purchase, stock take and optimises the life cycle cost. MMIS works together with the Supervisory Control and Data Acquisition System (SCADA). SCADA is a system that is constantly monitors and responds accordingly to any equipment failures. This system uses the data gathered from signalling, monitoring and telemetry systems, rolling stock sensors and also from manual input. These systems are designed to detect and prevent faults as early as possible to make it easier to manage and provide automatic advice to predict and correct these faults or oncoming problems. Shortening the maintenance time can be an effective measure to mitigate the train delays caused by technical failures, increases the capacity of lines, improves the safety of the railway network and overall improves the sustainability of HSR. Shinkansen has a large passenger demand and maintenance is mostly carried out at night time which leads to using the network exclusively for passenger needs. THSR high-speed rail in Taiwan introduced advanced equipment maintenance system, IBM Maxino, for real-time monitoring of assets. THSR has excellent performance with respect to punctuality and average delay per train which was 0.216 minutes per train in 2009 (Jong, 2010). A swiss TAMP is a project of Swiss Federal Railways that started in 2010 to develop a tool for predicted and preventive maintenance. It consists of track analysis and maintenance planning. Germany, Netherlands and France have already implemented computer models that make track maintenance decisions more efficiently.

3.3 Implementing modern signalling systems and traffic control systems

The signalling systems guarantee the safe movement of people and goods by railway. In the past, a combination of traffic lights and interlocking systems were used to control railway traffic. With the increase in train speed and volumes of traffic these systems are no longer efficient. Presently, many trains around Europe and the rest of the world are equipped with different navigation systems, such as Automatic Train Protection System (ATP), but these systems are extremely costly and occupy too much space on board. New technologies, state-of-the-art infrastructure and rolling stock require more advanced railway signalling systems. One example of the new generation of signaling systems is the Japanese Signal and Traffic Control System (DS-ATS). This system is used by Shinkansen trains. The system constantly calculates and automatically controls the speed of the train. Speed depends on the distance from the train in front and on the condition of the railway line ahead. The traffic control system provides real-time information on current train positions. DS-ATS system provides excellent safety and efficient records. This system increases the capacity of railway and reliability of services.

In Europe, a system called ERTMS (European Rail Traffic Management System) has been developed. This system consists of European Train Control System (ECTS level 1, level 2 and level 3), Global System for Mobile Communications-Railways (GSM-R) and Traffic Management Layer (Automatic Centralized Traffic Control). GMS-R is the mobile network for communication between driver and the train traffic control operator. ETCS Level 1 has line side signals and fixed blocks between trains. ETCS Level 2 has trackside devices for train detection and fixed blocks between trains. ETCS Level 2 is widely used on high-speed lines and it can replace the many incompatible safety systems currently used by European railways. This can improve the safety and cost efficiency of a railway. Implementing ETCS Level 2 will significantly reduce the delays caused by failure of signaling and train control systems. It can reduce the maintenance costs and provides better response to peak demand. The signal and interlocking failures are the main causes of train delays.

ETCS Level 3 is a train integrity, reporting mechanism with no fixed blocks and no trackside devices for train detection. ETCS Level 3 presumes that trains can be run very close to each other to maximise the capacity of line and rail system utilisation. It uses the satellite services for train positioning. It was estimated that the use of digital signaling systems can reduce the total delay by 35%, increases the capacity of a line by up to 40%, reduces maintenance and construction works, reduces the energy consumption by 15% and can be used as a bi-directional signaling system (Network Rail, 2016). ERTMS increases the safety of railway operations, increases capacity of lines and reliability of travel. However, this system needs further improvements. ERTMS uses the wireless communication signalling system (GSM-R) that is based on the public GSM technology and there is a possibility of interference in these systems. Some European countries have already introduced the new wireless signaling technology, but some gaps were found in their technology. For example, in the Netherlands and Belgium high-speed trains had disruptions by the loss of communication and were forced to stop unexpectedly (IMechE, 2013). The Netherlands Rail will be equipped with ERTMS by 2022 (Ballot, 2016). The Network Rail set the plan to implement ERTMS all over the UK by 2050.

With the increasing numbers of extreme weather events that affect the reliability of railway services advanced signaling systems can help to improve reliability and safety of the railway. ERTMS improves safety, speed, reliability and interoperability. The European Rail Traffic Management System helps increasing the capacity of existing railway lines by maximizing the benefit of the existing railway. By increasing the train speed, it will decrease the time and this will reduce the carbon dioxide emissions (Oxalis, 2013). ERTMS is the most advanced signaling system in world. This system uses wireless technology replacing the signals along the railway track. A computer inside the train cabin controls the speed limit of the train and breaking distance. The ERTMS system can automatically reduce the speed of the train if it exceeds the maximum allowed speed on that line. This system increases the safety of passengers traveling by train as it prevents human error. It reduces the operational and maintenance cost as there is no need to install and maintain signals along the railway tracks. It increases the capacity of tracks and improves the safety and reliability of journeys. The derailment of a high-speed train in 2013 in Spain that killed 80 people and injured 144 could have been prevented if ETCS had been fully functioning at that time (Langer, 2016).

3.4 Digitalised traffic management and timetabling

Disruptions in railway systems are unavoidable and there is a need to deal with them more effectively. It is important that infrastructure managers cooperate across the network borders to minimize any traffic disruptions and capacity restrictions when accidents occur. In order to solve the problem of disruption there is a need to reschedule the timetable, the rolling stock circulation and the crew duties- all of which are time-consuming to be solved manually. However, a computer programme was created to support this when disruptions occur. A computer programme can recognise and predefine availability for non-regular train paths based on the existing timetable, which would increase the capacity of existing networks. With the digitalization of traffic management processes, a railway system moves from a reactive approach to a much greater ability to predict, prevent and mitigate anticipated problems. This includes the continuous monitoring of infrastructure and rolling stock. The benefit of this is increasing the efficiency of railway systems, improving the safety, punctuality and quality of rail service. Digitalisation of traffic management processes will reduce the severity of a train delay caused by different kinds of incidents. In the Netherlands, in 2016 it was established that a new central Monitoring and Intervention Body including new traffic data management system will help solving disruptions on railway networks more quicker (Eringa, 2016).

3.5 Improving the staff skills through training and education

Employment in the transport sector in the EU is facing the challenges brought by the shortage of skilled staff and ageing of the population. Around 30% of the total number of employees are over 50 years old and they will retire in the next 10-15 years (EC, 2013a). It was predicted that by 2050 the working population in Germany will decline by 29%, in Portugal by 23% and in Italy and Spain by 11% (Arup, 2015**).** In the UK to maintain the current employment level, there will be a need to produce 10,000 engineers every year until 2020 (Watson, 2016). An ageing of the workforce and competition from other industries for skilled workforces created the shortage of staff. One example can be the Govia Thamslink Railway (GTR) franchise where almost 90% of trains run late due to staff shortage (Paton, 2016). The shortage of skilled staff in the railway industry could cost the UK economy more than £1 billion (Shamit, 2016).

The railway system depends on professionally trained, reliable and motivated people who can deliver efficient consumer-focused railway services. It needs to continuously improve staff skills to cope with the increasing demand for travel and new technologies and concepts such as “High Reliability Organizations” that railways are implementing. Lifelong learning principles are the key issue of high productivity of employees. The reliability of high-speed trains in Taiwan in 2015 was 99.66% (Table 1) and a major that keeps reliability so high is the excellent training of train drivers. They need to take an eight-month course with more than one thousand hours of professional training and pass the National Certification. After they successfully complete the training and pass exams, they need to take additional training at least three times a year. Training of drivers for Shinkansen is to a very high standard; drivers are arriving within 5 seconds of the scheduled arrival time at their destination and can stop the train within 1 centimetre of their stopping position. All crew members and station workers obtain regular training in case of any destruction of the network. Shinkansen carries 292 million passengers per year of which on the Tokyo-Osaka section there are around 130 million passengers per year. (Albalate, 2012), and with annual average delay 0.6 minutes/per train. To achieve such high level of punctuality, all staff of Shinkansen high-speed rail must perform exceptionally well. If any disruption occurs, well trained staff as soon as possible put traffic back to the scheduled timetable. There is not only exceptionally high standard of staff performances, but also the high level of technologies that is used by Shinkansen that contribute to keeping such a high level of punctuality. It is crucial to give the staff adequate training so that they can perform well but it is also important to create for them a comfortable work environment for high productivity. A comfortable working environment is another issue that can affect staff performance in relation to safety and punctuality of the railway network.

4. CONCLUSIONS

The analysis of the performance of HSR systems worldwide allows some common conclusions to be drawn in terms of the reliability of these systems. It seems that the most punctual HSR is the one that has two-track dedicated line (Shinkansen, THSR). The entire length of the track is secured by fences and screens to prevent any access to the line whilst there are no level crossings. These measures prevent any outside disruption of traffic. Dedicated tracks need less maintenance as most of the dedicated HSR are built on slab track; this also improves the reliability as less maintenance means less disruption to train traffic. The mix of traffic, i.e. freight, regional, local and HSR brings some disadvantages as in the case of Germany. For example, if trains with different speeds are allowed to use the same line then that will decrease the traffic capacity, reduces safety levels and reduces the reliability. It is difficult to produce a timetable for mixed lines to satisfy both the passenger traffic and freight because of the significant speed differences. It is difficult to allocate time for maintenance as most of the daylight time was allocated to passenger trains, but during the night the line is used by freight trains whilst maintenance is more frequent and longer than for dedicated lines. If the speed differences are more than 50km/h then the capacity of the line reduces dramatically. High-speed lines that have many level-crossings and lines not fully secured by fences and screens can experience delays. Debris that occurs on high-speed lines quite often affects the punctuality of services and the safety of passengers using such train services. Another reason for low punctuality is an outdated signaling system. Signal failure and interlocking failure are the major reasons for a train delay. Implementing advanced signaling systems such as ERMTS improves the reliability and safety, reduces the maintenance cost, increases the capacity of the railways and overall improves the sustainability of HSR. ERMTS is the most advanced control system in the railway industry and it is used for high-speed railways in many countries.

Implementing the preventive maintenance regime on the HSR network will increase the punctuality of trains and will keep unexpected breakdowns to a minimum. The Dutch government in the nineties substantially reduced the subsidies on railway maintenance but in return the punctuality of their railway system fell a few years later. One of the ways to reduce disruption of railway traffic is to combine different maintenance activities at the same time on the same site of the railway network as much as possible. Austria, Germany, The Netherlands and France have already implemented computer models that make track maintenance decisions more efficiently. Using the modern rolling stock equipped with advanced technologies that have high performances and offer high level of comfort for passengers is another way to improve the reliability of travel. Japan decided to change their rolling stock every 15-20 years. New and modern HSR system that has well equipped rolling stock would be more efficient, safe, and comfortable to use. In the UK for example, rolling stock is built to be used for 35-40 years before it needs an upgrade. To reduce the delay time, there is a need to improve traffic management in the presence of delays and disruptions. Digitalising traffic management and the use of advanced software help maintaining more efficient control of the flow of trains across the railway network and reduces delays and disruptions. The system automatically reschedules trains if a disruption occurs and it helps to reduce the time to recover normal train flow. In order to improve the reliability of HSR services and reduce the number accidents it is important to implement a culture of continuous technical learning for staff with broad training that includes the study of possible failures. The analysis of performance of the HSR systems suggests that improving reliability of HSR can improve safety, increases demand and capacity of rail and overall improves the sustainability of HSR.

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