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Binti Saadin, Sazrul Leena; Kaewunruen, Sakdirat; Jaroszweski, David

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REVISED TECHNICAL PAPER

# "Heavy rainfall and flood vulnerability of Singapore-Malaysia high speed rail system"

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by

**Sazrul Leena Binti Sa'adin**
Malaysian Land Public Transport Commission (SPAD)
Ministry of Transport, Kuala Lumpur, Malaysia

**Sakdirat Kaewunruen,**
Birmingham Centre for Railway Research and Education
The University of Birmingham

**David Jaroszweski**
Birmingham Centre for Railway Research and Education
The University of Birmingham

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Corresponding Author:

Dr Sakdirat Kaewunruen
Senior Lecturer in Railway Engineering
Birmingham Centre for Railway Research and Education
The University of Birmingham
Birmingham B15 2TT UK
Tel: +44 (0) 1214 142 670
E-mail: sakdirat@hotmail.com; s.kaewunruen@bham.ac.uk

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# Rainfall and flood vulnerability of Singapore-Malaysia high speed rail system

**Sazrul Leena Binti Sa'adin[1], Sakdirat Kaewunruen [2], and David Jaroszweski[3]**

**Abstract:** Change of climate is unequivocal, and many of the observed changes are unprecedented over five decades to millennia. It is expected that the global atmosphere and ocean is increasingly getting warmer, the amount of ice on the earth is decreasing over the oceans, and the sea level has risen. According to Intergovernmental Panel on Climate Change, such temperature change is around 0.78$^{o}$C over decades. However, it is highly likely that such change can trigger other extreme natural threats to interdependent urban and transport infrastructure systems. The vulnerability of those infrastructure systems has not been comprehensively addressed in open literature due to specific differences of local environmental and geographical conditions. As a result, our research will highlight the extremes that can lead to system failure, degraded operation and ultimately, delays to train services. The emphasis is placed on the newly proposed Malaysia-Singapore high speed rail network, which can be affected by the most-frequent severe weather conditions including heavy rainfall and flash flood. It is found that tunneling, steep cutting and ballast foundation are ones of the most vulnerable assets from a heavy rainfall or a flash flood.

**Keywords**: railway infrastructure, high-speed rail, tracks, risk, management and monitoring, climate change, global warming, adaptation, operational readiness, heavy rain, flood.

## 1. Introduction

High Speed Rail (HSR) has attracted increasingly interests worldwide from the policy makers in recent years including in Malaysia. HSR systems are becoming a backbone catalyst for economic, societal and regional growths. Their interdependency with other urban and transport systems creates

[1] Civil Engineer, Malaysian Land Public Transport Commission (SPAD), Ministry of Transport, Kuala Lumpur, Malaysia. E-mail: sazrul_leena@yahoo.com
[2] Senior Lecturer in Railway and Civil Engineering, Birmingham Centre for Railway Research and Education, The University of Birmingham, Birmingham B15 2TT UK. E-mail: s.kaewunruen@bham.ac.uk; sakdirat@hotmail.com
[3] Senior Research Fellow (Railway Geography), Birmingham Centre for Railway Research and Education, The University of Birmingham, Birmingham B15 2TT UK. E-mail: D.J.Jaroszweski@bham.ac.uk

an alternative and sustainable transport substitute while its independency paves the robust pathway for coexistence with other transport modes (Kaewunruen et al., 2015; 2016). In the creation of this new form of transportation, the infrastructure owners need to ensure that the new HSR can cope and adapt to the potential climate change in the particular region. It is found that complexities of climate change and predictions of climate model outputs have introduced an additional measure of uncertainty for railway operators (Remennikov and Kaewunruen, 2008; Remennikov et al., 2012). Extreme weather conditions play an important role in railway operations and safety, including fatalities, injuries and property damage. Despite climate change posing serious challenges to infrastructure projects, little research has been conducted in Malaysia into how vulnerable it will be especially to the transport infrastructure. It has been widely recognized that there is a need to integrate consideration of climate change and its impacts in development policies and projects (Kramer et al., 2010). The decision making today must take into account the consequences that could affect the new assets and infrastructures in the future.

High Speed Rail from Kuala Lumpur, Malaysia to Singapore (HSR), which is still in its planning stage, would be the first of its kind in Malaysia. Prime Ministers of Malaysia and Singapore jointly announced the project of HSR on the 19th February 2013 and described the HSR as a 'Game Changer' (Land Public Transport Commission, 2015). The project milestone is to be fully operational by 2020. The key concept of the HSR derived by Malaysian Land Public Transport Commission (SPAD), will have 7 stations, 2 Terminus stations, which are in Kuala Lumpur and Singapore. 5 transit stations, each is in Negeri Sembilan, Malacca and 3 in Johor. The HSR will have 2 operation systems, which are express, non-stop journey from Kuala Lumpur to Singapore and estimated journey time is 90 minutes, while HSR Malaysia transit operation will have 7 stops including at terminus station will experience a 120 minutes journey time. This journey time does not include the waiting time and immigration process. The trains are expected to run at 300km/hour or faster however average speed will be lower due to the slower speed to approach the stations. Baseline alignment has been developed by SPAD as shown in Figure 1 below, but the detailed alignments remain confidential at this stage. The HSR will have a dedicated line, which is proposed to be a double track on a standard gauge. The HSR project is believed to impact the way of life for Malaysians and Singaporeans in terms on social, politics and economics. According to SPAD, the main objective of HSR is "*to reduce travel time between Kuala Lumpur and Singapore to 90 minutes by strengthening the link between two of Southeast Asia's most vibrant and fast-growing economic engines compared to the 5 to 6 hours journey time by road or 8 hours by conventional train*" (Land Public Transport Commission, 2015).

Although the travel time by plane is 90 minutes similar to that by the proposed HSR but the hassle of long hours waiting before and after departures will actually give total journey time of 2.5 hours by plane (News Straits Times, 2013). Contrary to the airplanes, train passenger still can board the HSR even though they arrive at the railway station 15 minutes before departure. Note that CBD shown in Figure 2 stands for 'Central Business District'. The introduction of HSR will increase the daily journey from KL to Singapore and vice versa and at the same time, life quality for both countries people will be improved as well as the economics of both countries will be stronger. The HSR, according to International Union of Railways (UIC, 2011; 2015), has a lower impact on climate and environment than all other compatible transport modes such as aviation and road transport, which are highly dependable on fossil fuels. Adoption of HSR might give a better solution in reducing the climate impact.

Despite strong commitment from both Malaysian and Singaporean Governments, the lack of progress can be observed and has given a window of opportunity to include the climate change risks and adaptation strategy into the detailed design stage of the HSR system. Despite numerous climate change research around the world, its application to risk assessment for high speed rails in Asia is not thoroughly investigated. This is because georisk hazards and their sensitivity to climate change cannot be directly cross transferred without full consideration of local conditions. As a result, there is a necessity to assess climate change risk to high speed rail infrastructure at the design and construction stages. The aim of this paper is to highlight flood risks imposed on the high speed rail system caused by local conditions including topographical, geological and climatic variations along the proposed HSR route in Malaysia. Such the insight will help rail engineers to better design and construct the high speed rail infrastructure that is critical to economic growth of cities and regions.

## 2. Climate, Geography and Lessons Learnt

Malaysia is divided into 2 parts, Peninsular Malaysia and East Malaysia. Peninsular Malaysia however is alienated by 2 parts, west and east coasts by the Titiwangsa Mountains.

The climate in Malaysia is dominated by 2 monsoon regimes namely as northeast monsoon and southwest monsoon. The northeast monsoon circulates during the months of December, January and February, which is Malaysia's wettest season and the period where the most flooding occurs. Meanwhile the southwest monsoon occurred between the months of May and September, the drier period for the whole country leading to droughts at this period. Being in the equatorial zone and tropical country, the average temperature throughout the year is constantly high (26°C) and has a very high humidity due to the high temperature. Malaysia also has very heavy rainfall which is more than 2500mm per year.

"Warming of the climate system is unequivocal and since the 1950s, many of the observed changes are unprecedented over decades to millennia" (Pachauri and Meyer, 2014). According to Malaysia Meteorological Department (2009), earth surface temperature records have clearly indicated that the climate of the earth is warming, with the rise being due to the increasing concentration of greenhouse gases (GHG) in the atmosphere. Thus, Malaysia will experience higher temperatures, changing rainfall patterns, rising sea levels and more frequent extreme weather events ranging from drought to floods in the next 50 year. The Malaysian famous rail jungle (east coast line), which is operated by National Malaysia Railway (KTM) was disrupted for almost 6 months due to the massive flood in December 2014. The damage included the railway quarters, signalling, tracks, locomotives, machinery and rolling stock. The disruption affected thousands of workers, traders and children going to school. There is still one stretch of line still not back in operation due to the railway bridge in Kemubu, Kelantan had completely collapsed as evidenced in Figure 3.

Operation of the train service in the east coast is expected to be fully operational by February 2016 with the completion of the railway bridge in Kemubu. Construction of the new 250m long bridge across the Nenggiri River is expected to cost RM30 million or GBP4 million (theSundaily, 2015). This incident should give a lesson to the railway industries and policy maker that extreme weather can have a severe impact to the transportation operations as well as to their infrastructure (Bringinshaw, 2014; Krezo et al., 2016; Leclerc, 2012; Nash, 2013, Smith, 2014). Rebuilding railway infrastructure is not easy and very costly thus to provide a reliable railway system into the future, studies of the impact of climate change is needed. From these studies, the adaptation of railway infrastructures and rolling stock to the climate change could be established.

## 3. Risks of heavy rainfall and flows to Railway Infrastructure

Extreme weather events have occurred frequently in Malaysia the past decade. Previous studies by the authors have identified key environmental risks as shown in Table 1. The most devastating natural disasters experienced in Malaysia are floods and their consequential landslides. This paper will thus pay special attention to the risks associated with heavy rainfall and flood.

### 3.1) Increased rainfall

#### a) Terminals

The HSR terminus station in Kuala Lumpur (capital city of Malaysia) will be located at a new development called Bandar Malaysia, which previously is the location of Sungai Besi Royal Malay Aircraft Force (RMAF) shown in Figures 4 and 5. HSR Malaysia will start construction concurrently which is expected to kick off in 2017. Thus, the case study 1 will be based in Kuala Lumpur starting from Bandar Malaysia in Kuala Lumpur towards the southern of Malaysia before reaching the next HSR Malaysia station in Seremban.

Kuala Lumpur is known as a limestone area, where karst has significantly established. In which, karst is a geological formation shaped by dissolution of a layer of layers of soluble bedrock, usually carbonate rocks such as limestone or dolomite. According to Zabidi and Freitas (2006), this karst could be classified as Extreme Karst, class kV and can be considered to occur in Kuala Lumpur at two scales; the smaller scale is that of a buried karstic landscape with highs and lows to bedrock depth below an almost horizontal ground level; the larger scale is that of the limestone below bedrock where discontinuities have been opened by dissolution and caves created, many of which have collapsed and are partially filled. This latter type of karst created a lot of problems during the structural foundation design and construction and perhaps to HSR construction later on in which had happened near to the MRT site in Bukit Bintang area in Kuala Lumpur. The mid-morning incident happened along a 19m stretch at the busiest road in KL namely Jalan Pudu-Jalan Imbi-Jalan Hang Tuah intersection, ending with a 10m deep sinkhole just 20m from the elevated KL Monorail track near the Imbi Station. It was reported that the huge sinkhole was due to the burst water pipe as shown in Figure 6. The sink holes refer to a depression on the ground surface caused by dissolution of the limestone near the surface or the collapse of an underground cave. The main triggering factors that develop sinkholes are lowering of groundwater tables, loss of fines through groundwater seepage, imposing of additional loads and vibrations. Thus, through the climate change the extreme rainfall might cause extra groundwater flow stimulating the movement of fines in the soil into channels and eventually triggering the sinkholes.

**b) Geology Hazard and Solution**

Mostly, the HSR alignment in KL will pass through either via viaducts or tunnelling. Thus, the Government or authorised body involved in HSR Malaysia need to do a risk analysis especially of the sinkhole circumstances for both viaduct and tunnelling constructions, the impact is just the same. The viaduct through the piling construction in the karst area will have an uneven length of piling. The piling that is set just above the cavities, will affect the foundation in the long term. However, piling activities will trigger the sinkholes in the construction area as well. Karst on the other hand in the tunnelling construction may result in the loss of slurry and experience instability. A sufficient size of karst might lead to difficulties in handling or steering a TBM.

There have been some construction solutions since MRT in Malaysia has experienced during tunnelling construction; and HSR Malaysia developer could use their previous experience and records in handling the TBM in the karst area. To tackle the problem, the MRT Corp (the developer and asset owner of the MRT project in Kuala Lumpur) carried out a detailed geotechnical investigation, TBM selection and ground treatment. For ground treatment groundwater jet grouting, compaction grouting and fisher grouting will be performed at weaker ground strata and to fill cavities. In order to reduce the blow and sinkholes, variable density TBM is introduced. The variable density TBM is an extended version of a slurry version TBM. The machine is able to use high density slurry to prevent the blow out of slurry and sinkholes. The machine can be operated in Earth Pressure Balance (EPB) and conventional slurry mode. In order to avoid the soft ground from falling in during tunnelling process, the EPB TBM uses the excavated material to provide the support for the drill face. Nozzles at the front of the drill head inject foam into the soil before the drills face cut into it, and turns the excavated earth into a more liquid and malleable substance (MRT Corp, 2015). Development of this machine, however was based on the experiences faced by MGKT (contractor for the underground portion for the Klang Valley MRT project) from the previous project named SMART Tunnel. The SMART tunnel alignment transverse the same karstic limestone ground conditions and with a larger diameter single dual purpose tunnel to alleviate the flood and carry traffic at the same time. Where the SMART tunnel project experienced a lot of sinkhole incidents occurred while tunnelling construction. This had given a lot of social impact such as traffic jams and damage to the roads and surrounding properties. According to MMC-Gamuda KVMRT (T) Sdn Bhd (2015), the number of major sinkholes on the 2 projects, each involving similar lengths, albeit different diameters, the reduction from more than 41, as shown in Figure 7.

This lesson informs us that the machine itself is not enough to prevent the sinkhole from happening. There is a significant chance that all sinkholes that had happened in Malaysia were due to construction activities as mentioned earlier (Binti Sa’adin et al., 2016a; 2016b). Precautions such as detection of ground movements, detection of underground water locations, extreme weather predictions, and detection of utilities locations are very much needed especially to those areas that have higher chance of localised higher ground movement. Therefore, a good judgment in an engineering decision is very advisable. The Government also on the other hand through their Council and Ministry Housing have these records from all the projects such as Soil Investigation records, Geotechnical Reports, and Progress Reports and from there on, studies should have been made based on the studies on those projects so they can be used as guidelines or lesson learnt for future projects. There have been guidelines that each Government project needs to do risk assessments before the project kick off however there is also a need to have a risk based approach addressing a wide range of events of extreme weather. It is therefore found that Table 1 provides a suitable adaptation measure for heavy rainfall risk in Kuala Lumpur area whereas the limestone and other carbonate rocks (dolomite and marble) are very soluble in rainfall. Thus, with this information, the policymaker or HSR developer could study the potential karst area on the HSR Malaysia route (United Nations University, 2005; Binti Sa'adin et al., 2016c). Then, it is important to develop the adaptation policy evaluation tools as shown in Table 2. The heavy rainfall can also trigger a flash flood. It is thus important to ensure that the track drainage design, operation and maintenance are carried out appropriately in order to cope with the higher risks of heavy rainfall and flash flood. Any slope, embankment and cutting should be gentle to reduce runoff speed and soil/granular erosion.

**3.2) Floods**

Among all the natural disasters, flooding is the most frequent disaster in Malaysia. Malaysia's worst flood in Johor happened twice in December 2006, and the second wave in January 2007 had destroyed 60,000 houses with 16 reported deaths. Infrastructures such as highways, bridges and railway tracks had been submerged and lost connectivity to the effected districts. The electricity and water supply were also affected. Malaysia's Drainage and Irrigation Department has described the flood as the worst in Johor in a century. According to the Science, Technology and

Innovation Minister Datuk Seri Dr Jamaluddin Jarjis said the heavy rainfall was brought by strong winds from the South China Sea and Western part of the Pacific Ocean, the after-effect Typhoon Utor, which hit the Phillipines. The massive flood was not coming from the monsoon rains but due to climate change. The areas that were badly affected with flood included Batu Pahat and Kota Tinggi (southern part of Peninsular Malaysia). In this case, the HSR alignment proposed by SPAD, will transverse and even stop at Batu Pahat, Johor (transit service).

A flood is any water flow that exceeds the capacity of the drainage system and usually subsides in a relatively shorter period. In Malaysia, the flood that hit Batu Pahat District was different from the other districts. Batu Pahat flooding extended for 48 days from the first wave until it subsided fully. Past major flooding events for the state of Johor, Malaysia were recorded in 1926, 1967, 1968 and 1971. However, major meteorological phenomena that hit Johor on the 19th December 2006 (first wave) and the 12th January 2007 (second wave) were claimed to be the worst flood disaster in Johore in a 100 years. All eight districts were affected displacing 157,018 and 155,368 population during the first and the second wave even respectively. (Badrul Hisham et al., 2009). According to IPCC (2014), there is high confidence based on their studies that coastal systems and low lying areas will increasingly experience submergence, flooding and erosion throughout the 21st century and beyond, due to sea level rise. Thus, the flooding in the low lying area of Johor will become more vulnerable to the massive flood in the near future. Based on the studies by Ahmad Radzi and Ismail (2013), Kukup, Johor is predicted to have an additional mean sea level of 7.247cm and 14.9cm in 2050 and 2100 respectively. This result also indicates that Straits of Malacca will experience the sea level rise in the future, thus lead to the Government to consider the sea level rise to their design of High Speed Rail track formation level. The flood water can also undermine track foundation such as ballast washaway, embankment failure, land slip/slide, and so on. In addition to the good condition of drainage design at all time, the flood water protector should be constructed in vulnerable areas such as low-terrain tracks, railway junction, and major drainage infrastructures. These measures will minimise the effects of flood water flow and also the high-speed movement of flood-borne debris.

## 4. Concluding Remarks

Climate change is real and unequivocal. Malaysia is still far behind in terms of assessing the risks of climate change especially to the railway operation. There was a lack of studies on the effect of climate change to the Malaysian railway operation and as well to the railway infrastructures. The risk, safety and performance impact from each climate impact group to the operation of HSR Malaysia is thus highlighted in this paper. The potentials of heavy rainfall and flood on the HSR system have been evaluated considering local geological, topological and environmental conditions. Suitability of climate change adaptation measures has then be evaluated and proposed for inclusion in the design consideration of the HSR system in Malaysia and Singapore as shown in Table 3. The outcome of this study recommends that all authorities including the Ministry of Transport, KTMB, SPAD and relevant authorities work together to build resilient infrastructures and to ensure that the operation of HSR Malaysia will not disrupted in the event of extreme weather. The resilient infrastructure should consider enabling both the preventive measures (pre-disaster) and the quick recovery and repair techniques (post-disaster).

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resilience in the face of physical natural and unnatural threats, as well as advanced sensing under extreme conditions (www.risen2rail.eu).

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**Table 1** Risks and adaptation measures for high speed rail in Malaysia

| Climate Impact Group | Risks | Safety Impact | Performance Impact | Likely Negative Impact from Climate Change | Long or Short Term* | Adaptation Measures |
|---|---|---|---|---|---|---|
| **Sea Level Rise** | Increased flooding generally | Medium | High | High | Long | Platform level need to cater to sea level rise and drainage design must cater to ARI plus climate change projection. |
| **Increased Rainfall** | Landslide | High | High | High | Long | Drainage design must cater to ARI plus climate change projection |
| **Increased Rainfall** | Settlement | High | High | Low | Long | Need to monitor the ground movement and the relation with rainfall intensity especially at the karst area in Kuala Lumpur. |
| **Heat** | Track buckling | High | High | High | Long | Need to study on rail design resilient to high temperature or provide watchmen |

*a short term effect lasts over a duration of less than a day, whilst a long term one lasts over a day.

**Table 2** Potential mitigation and adaptation solutions at the potential settlement area due to increase rainfall

| **Potential mitigation and adaptation solutions** |
|---|
| Established route alignment associate with potential karst area. |
| Establish the severity of the settlements before this. How do these events compare to other rainfall events in recent history. |
| An interactive mapping visualisation tool to show the most dangerous karst area and the potential location where rainfall could intercept into the karst area. |
| Study in detail the effect. Method of construction Tunneling or Elevated structures is more suitable in those affected areas. |
| If Tunneling, which TBM should be used? |
| Precaution while construction at those affected areas such as installation of cofferdam. |
| Install inclinometres or any apparatus that could monitor settlements at all the potential risky areas. Should allocate control rooms for risk disaster for KL-Singapore HSR. |

**Table 3** Proposed planning process for climate change adaption for HSR Malaysia

| **No.** | **Planning Component** | **Purpose** |
|---|---|---|
| **1** | Critical weather events | Knowledge and understanding of impact on HSR Malaysia |
| **2** | Critical components of HSR Malaysia | Knowledge and understanding of vulnerability to critical weather events |
| **3** | Prediction of climate change impact | Methodology for predicting the impact of specific critical weather events on components of the HSR Malaysia |
| **4** | Development of adaptation options | Permits evaluation of different adaptation policies |
| **5** | Design standards | Identification of changes to design standards to mitigate the impact of climate change |
| **6** | Management policy | Identification of changes to management policy to mitigate the impacts of climate change |

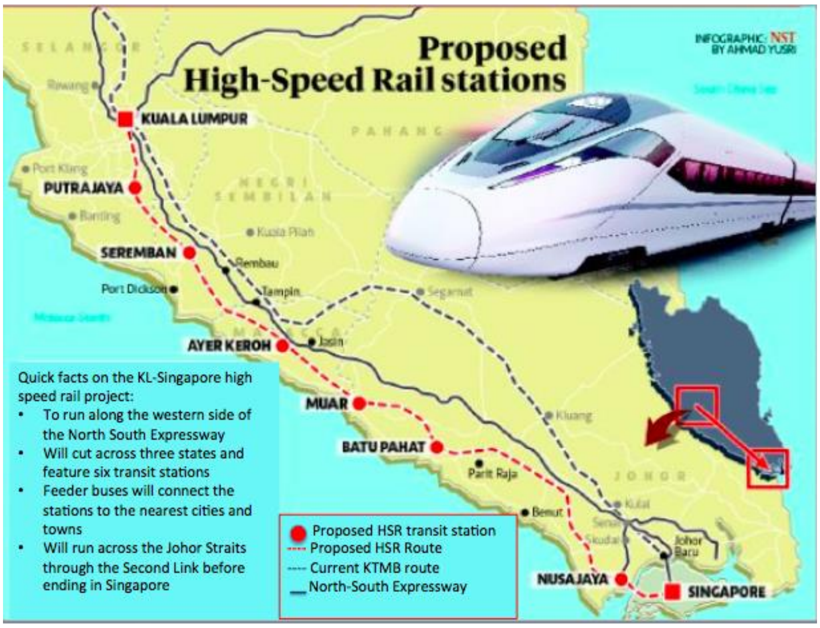


**Figure 1**: Proposed High Speed Rail Malaysia to Singapore (Courtesy: SPAD)

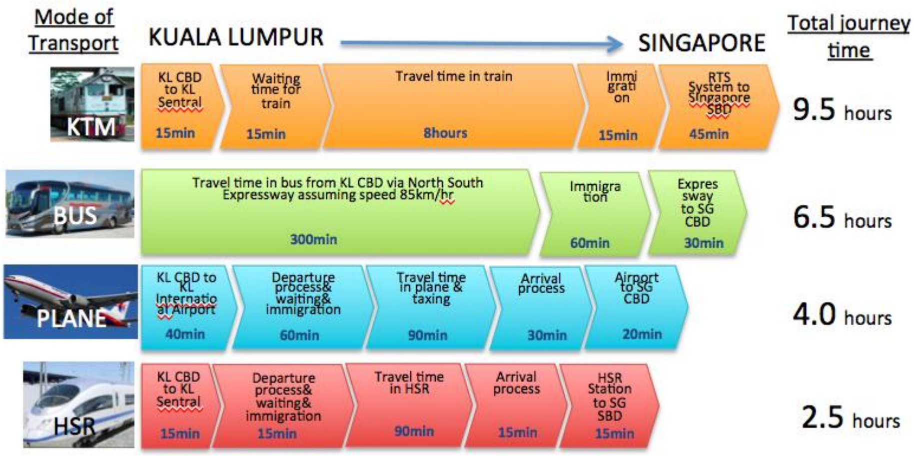


**Figure 2**: Travelling time from KL to Singapore comparison between KTM, Bus, Plane and HSR (Courtesy: SPAD)

**Figure 3**: Malaysia East Coast Line railway bridge, which cross Nenggiri River in Kemubu, Kelantan had totally lost due to massive flood in December 2014. (Courtesy: SPAD)

**Figure 4**: The terminus station at Kuala Lumpur, previously is the location of Sungai Besi Royal Malay Aircraft Force (RMAF) (Courtesy: SPAD)

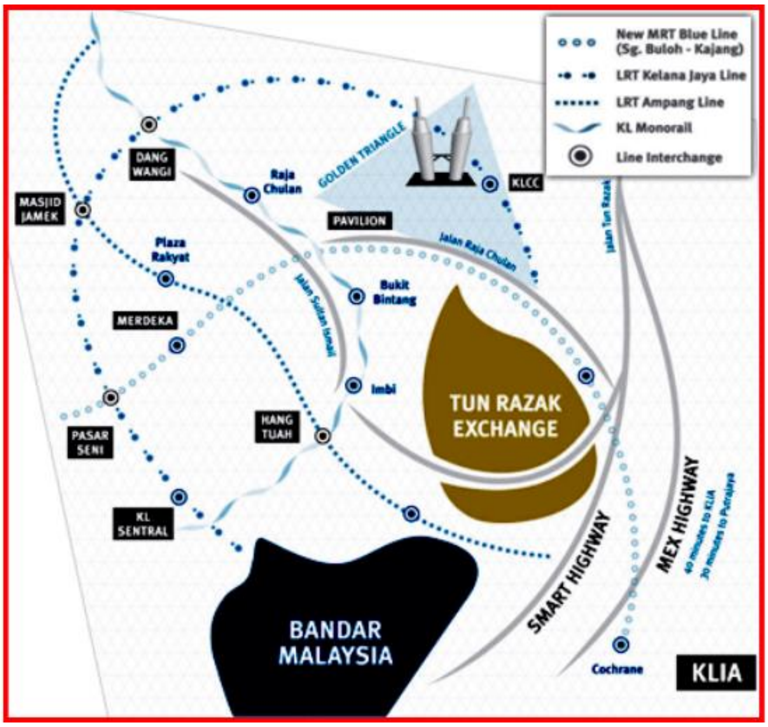


**Figure 5**: Terminus HSR Station and public transport surrounding at Bandar Malaysia (Courtesy: MRT Corp)

**Figure 6**: A 10m deep sinkhole happened in Bukit Bintang near to MRT construction (Courtesy: MRT Corp)

**Figure 7**: Sinkholes at Jalan Bukit Bintang 6m from MRT tunnelling construction (Courtesy: MRT Corp)