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REVISED TECHNICAL PAPER

“Heavy rainfall and flood vulnerability of Singapore-Malaysia high speed rail system”

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

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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°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

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

92 High Speed Rail from Kuala Lumpur, Malaysia to Singapore (HSR), which is still in its
93 planning stage, would be the first of its kind in Malaysia. Prime Ministers of Malaysia and
94 Singapore jointly announced the project of HSR on the 19th February 2013 and described the HSR
95 as a ‘Game Changer’ (Land Public Transport Commission, 2015). The project milestone is to be
96 fully operational by 2020. The key concept of the HSR derived by Malaysian Land Public Transport
97 Commission (SPAD), will have 7 stations, 2 Terminus stations, which are in Kuala Lumpur and
98 Singapore. 5 transit stations, each is in Negeri Sembilan, Malacca and 3 in Johor. The HSR will
99 have 2 operation systems, which are express, non-stop journey from Kuala Lumpur to Singapore
100 and estimated journey time is 90 minutes, while HSR Malaysia transit operation will have 7 stops
101 including at terminus station will experience a 120 minutes journey time. This journey time does
102 not include the waiting time and immigration process. The trains are expected to run at 300km/hour
103 or faster however average speed will be lower due to the slower speed to approach the stations.
104 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

131 system caused by local conditions including topographical, geological and climatic variations along
132 the proposed HSR route in Malaysia. Such the insight will help rail engineers to better design and
133 construct the high speed rail infrastructure that is critical to economic growth of cities and regions.

134 **2. Climate, Geography and Lessons Learnt**

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

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

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

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

166

167 **3. Risks of heavy rainfall and flows to Railway Infrastructure**

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

172

173 **3.1) Increased rainfall**

174 **a) Terminals**

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

181 Kuala Lumpur is known as a limestone area, where karst has significantly established. In
182 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.

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

231 This lesson informs us that the machine itself is not enough to prevent the sinkhole from
232 happening. There is a significant chance that all sinkholes that had happened in Malaysia were due
233 to construction activities as mentioned earlier (Binti Sa'adin et al., 2016a; 2016b). Precautions such
234 as detection of ground movements, detection of underground water locations, extreme weather

235 predictions, and detection of utilities locations are very much needed especially to those areas that
236 have higher chance of localised higher ground movement. Therefore, a good judgment in an
237 engineering decision is very advisable. The Government also on the other hand through their
238 Council and Ministry Housing have these records from all the projects such as Soil Investigation
239 records, Geotechnical Reports, and Progress Reports and from there on, studies should have been
240 made based on the studies on those projects so they can be used as guidelines or lesson learnt for
241 future projects. There have been guidelines that each Government project needs to do risk
242 assessments before the project kick off however there is also a need to have a risk based approach
243 addressing a wide range of events of extreme weather. It is therefore found that Table 1 provides a
244 suitable adaptation measure for heavy rainfall risk in Kuala Lumpur area whereas the limestone and
245 other carbonate rocks (dolomite and marble) are very soluble in rainfall. Thus, with this
246 information, the policymaker or HSR developer could study the potential karst area on the HSR
247 Malaysia route (United Nations University, 2005; Binti Sa'adin et al., 2016c). Then, it is important
248 to develop the adaptation policy evaluation tools as shown in Table 2. The heavy rainfall can also
249 trigger a flash flood. It is thus important to ensure that the track drainage design, operation and
250 maintenance are carried out appropriately in order to cope with the higher risks of heavy rainfall
251 and flash flood. Any slope, embankment and cutting should be gentle to reduce runoff speed and
252 soil/granular erosion.

253

254 **3.2) Floods**

255 Among all the natural disasters, flooding is the most frequent disaster in Malaysia.
256 Malaysia's worst flood in Johor happened twice in December 2006, and the second wave in January
257 2007 had destroyed 60,000 houses with 16 reported deaths. Infrastructures such as highways,
258 bridges and railway tracks had been submerged and lost connectivity to the effected districts. The
259 electricity and water supply were also affected. Malaysia's Drainage and Irrigation Department has
260 described the flood as the worst in Johor in a century. According to the Science, Technology and

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

267 A flood is any water flow that exceeds the capacity of the drainage system and usually
268 subsides in a relatively shorter period. In Malaysia, the flood that hit Batu Pahat District was
269 different from the other districts. Batu Pahat flooding extended for 48 days from the first wave until
270 it subsided fully. Past major flooding events for the state of Johor, Malaysia were recorded in 1926,
271 1967, 1968 and 1971. However, major meteorological phenomena that hit Johor on the 19th
272 December 2006 (first wave) and the 12th January 2007 (second wave) were claimed to be the worst
273 flood disaster in Johore in a 100 years. All eight districts were affected displacing 157,018 and
274 155,368 population during the first and the second wave even respectively. (Badrul Hisham et al.,
275 2009). According to IPCC (2014), there is high confidence based on their studies that coastal
276 systems and low lying areas will increasingly experience submergence, flooding and erosion
277 throughout the 21st century and beyond, due to sea level rise. Thus, the flooding in the low lying
278 area of Johor will become more vulnerable to the massive flood in the near future. Based on the
279 studies by Ahmad Radzi and Ismail (2013), Kukup, Johor is predicted to have an additional mean
280 sea level of 7.247cm and 14.9cm in 2050 and 2100 respectively. This result also indicates that
281 Straits of Malacca will experience the sea level rise in the future, thus lead to the Government to
282 consider the sea level rise to their design of High Speed Rail track formation level. The flood water
283 can also undermine track foundation such as ballast washaway, embankment failure, land slip/slide,
284 and so on. In addition to the good condition of drainage design at all time, the flood water protector
285 should be constructed in vulnerable areas such as low-terrain tracks, railway junction, and major

286 drainage infrastructures. These measures will minimise the effects of flood water flow and also the
287 high-speed movement of flood-borne debris.

288

289 **4. Concluding Remarks**

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

303

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311 which enables a global research network to tackle the grand challenge of railway infrastructure

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

314

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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

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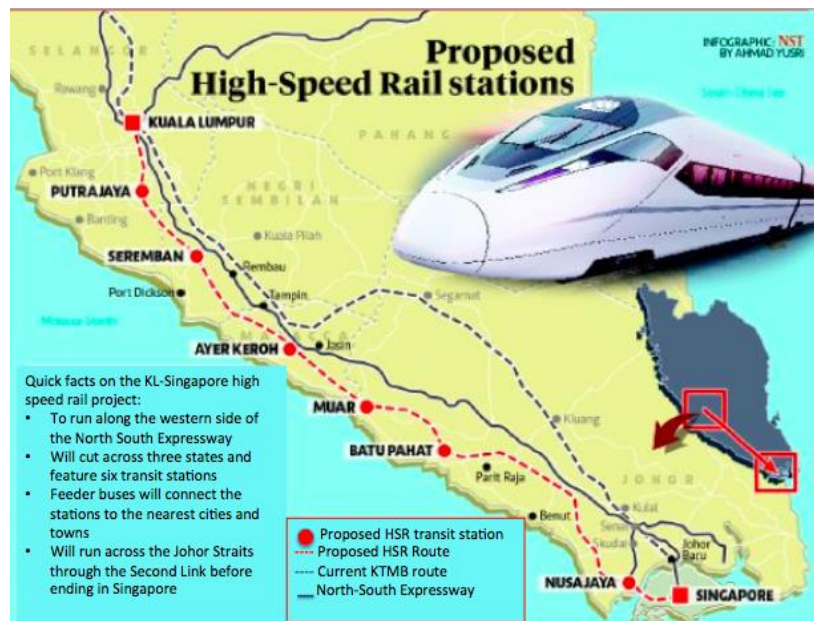


Figure 1: Proposed High Speed Rail Malaysia to Singapore (Courtesy: SPAD)

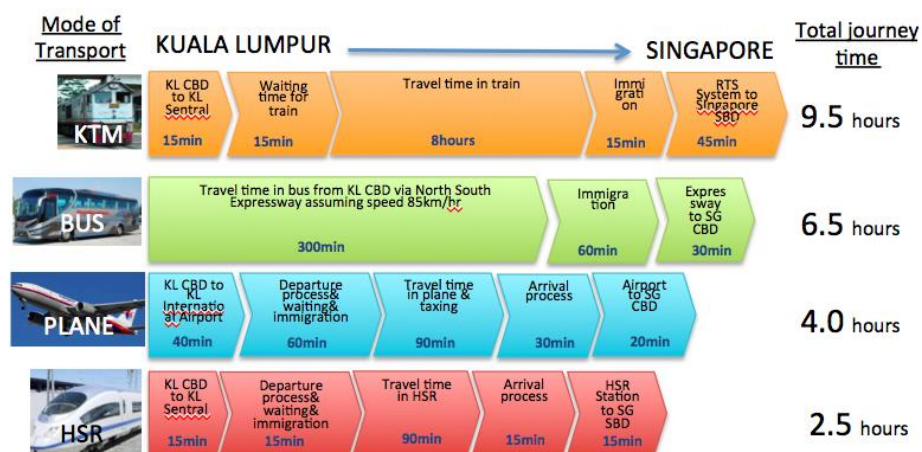


Figure 2: Travelling time from KL to Singapore comparison between KTM, Bus, Plane and HSR (Courtesy: SPAD)



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)

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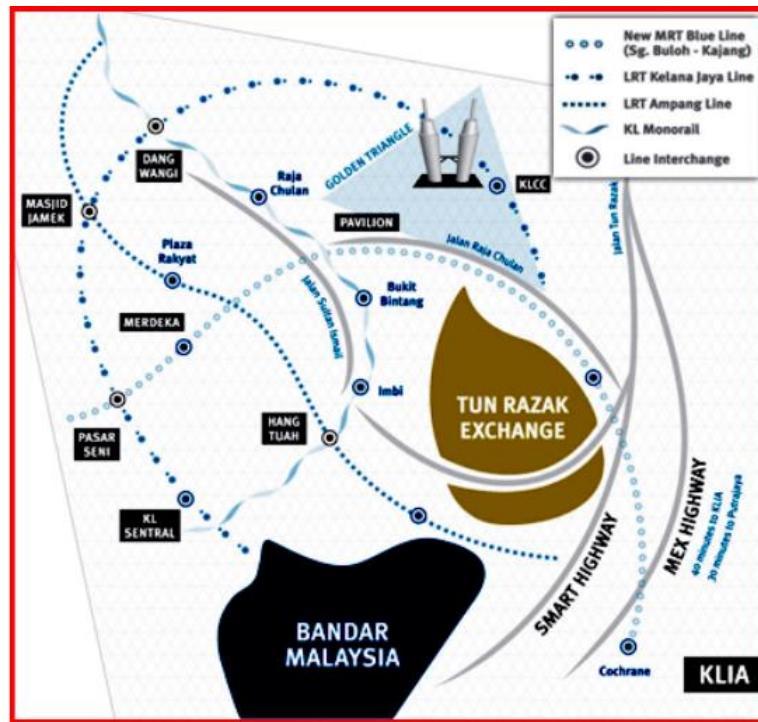


Figure 5: Terminus HSR Station and public transport surrounding at Bandar Malaysia (Courtesy: MRT Corp)

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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)